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HARACTER AND RECENCY OF FAULTING, SAN DIEGO METROPOLITAN AREA, CALIFORNIA

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CHARACTER AND RECENCY OF FAULTING, SAN DIEGO METROPOLITAN AREA, CALIFORNIA

By

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ABSTRACT

The San Diego greater metropolitan area is complexly dissected by Quaternary faults. These faults lie within three major northwesterly striking zones: Rose Canyon, Point Loma, and La Nacion. Together these fault zones lie within a 20 km (kilometer) wide belt that extends from La Jolla on the north to the U.S.-Mexican boundary and beyond on the south. Individual faults within these zones are as much as 8 km in length, although the average length is less than 1 km.

A minimum and/or maximum age is assigned to the displacements associated with each fault where the age of strata faulted or not faulted is known. The youngest strata known to be faulted belong to the upper Pleistocene Bay Point Formation (approximately 1.2×10^5 years). Because these strata are not commonly overlain by Holocene sediments, it has not been possible to determine if overlying Holocene sediments are faulted. The late Pleistocene age assigned such faults represents the maximum age for their most recent movement. Along the Rose Canyon fault zone an average rate of 1-2 m/10^3 years (meters per thousand years) strike slip and 10-15 cm/10^3 years (centimeters per thousand years) dip-slip separation has occurred since late Pliocene time. The amount of separation along the Rose Canyon fault zone associated with any one earthquake is unknown as is the total amount of possible aseismic creep.

Further geophysical work in the San Diego area could help answer questions dealing with potential ground accelerations, recurrence intervals of earthquakes, and exact locations of faults buried beneath the deeply alluviated and offshore areas. Exploratory trenching and drilling combined with seismic refraction and gravity traverses within the south San Diego Bay and Tijuana Valley areas, shipboard reflection profiling of the inner continental shelf area adjacent to San Diego, and additional detailed fault mapping within the Rose Canyon and La Nacion fault zones should also help provide better answers to these questions.

CHARACTER AND RECENCY OF FAULTING, SAN DIEGO METROPOLITAN AREA, CALIFORNIA

by Michael P. Kennedy[1], Sean Siang Tan[1],
Rodger H. Chapman[2], and Gordon W. Chase[2]

INTRODUCTION

This report presents the initial findings of an investigation of the character and recency of faulting in the San Diego greater metropolitan area, California (figure 1), which extends from La Jolla south to the U.S.-Mexican border, and from the coast inland approximately 20 km. The study was conducted during 1973-74 by the California Division of Mines and Geology and was supported by the U. S. Geological Survey as part of their earthquake hazards reduction program. The main product of the study is the 1:50,000 scale fault map (plate 1) that shows the age, character, and location of faults within the area studied.

Faults were studied by on-site field investigations; exploratory trenching and drilling; high-altitude imagery; stereo and low-altitude imagery; stereo and low-altitude oblique photography; magnetic, seismic, and gravity geophysical measurements; and shipboard subbottom acoustic profiling. The details of the subbottom acoustic profiling are reported elsewhere (Moore and Kennedy, 1975).

Over-all responsibility for this report lies with the senior author, M. P. Kennedy; he and Tan are responsible for plate 1, the illustrations, and the text on tectonic setting and faults. Chapman and Chase are responsible for plate 2 and the chapter on geophysical observations.

The base map was prepared from the La Jolla, Point Loma, La Mesa, National City, and Imperial Beach 7.5-minute U. S. Geological Survey quadrangles. The stereo photographs used and their scales include U. S. Geological Survey 1966 (1:25,000), 1971 (1:30,000), and U. S. Department of Agriculture 1953 (1:12,000). The low altitude oblique photographs were taken especially for this project by the senior author from fixed wing aircraft on 35 mm film; the high altitude imagery used was 1973 ERTS (1053-17554).

Previous investigations of fault activity in San Diego that greatly aided this study include a report on the recency of faulting in the greater San Diego metropolitan area by Ziony and Buchanan (1972) and a study of the northern offshore extension of the Rose Canyon fault zone by Moore (1972). Discussions with D. M. Morton, G. W. Moore and J. I. Ziony of the U. S. Geological Survey; with C. H. Gray, Jr., J. E. Kahle, and F. H. Weber of the California Division of Mines and Geology are greatly appreciated.

TECTONIC SETTING

Major faults in the San Diego area lie subparallel to the tectonic grain dominated by faults of the San Andreas system. Within the area investigated, the most prominent faults mapped strike northwest. The observable traces of these faults are as much as 8 km (kilometers) in length but average less than 1 km. These are generally discontinuous en echelon faults that as a group form what have been mapped in previous studies as continuous throughgoing structures (e.g., Kennedy and Moore, 1971).

Quaternary dip-slip faults that are genetically and temporally closely associated with major strike-slip faulting at San Diego are abundant. The largest of these faults are associated with the La Nacion, Rose Canyon and Point Loma fault zones as well as with fault zones underlying San Diego Bay, offshore bight, and the Tijuana flood plain.

The maximum Quaternary vertical separation associated with the La Nacion fault zone is 100 m (meters), based on the structural deformation of the Lindavista Terrace (figure 2). The southern part of San Diego Bay and the Tijuana River Valley are underlain by a multi-stepped graben that is bounded on the east by the La Nacion fault zone and on the west by faults that lie offshore from the mouth of the Tijuana River. This graben extends north and is seen in an east oriented section measured between National City and Point Loma across the northern part of San Diego Bay where it appears to be formed along fewer step faults than to the south, but with each having a greater amount of separation. The vertical separation of the Lindavista Formation between these points, measured on the Point Loma

[1]Geologist.
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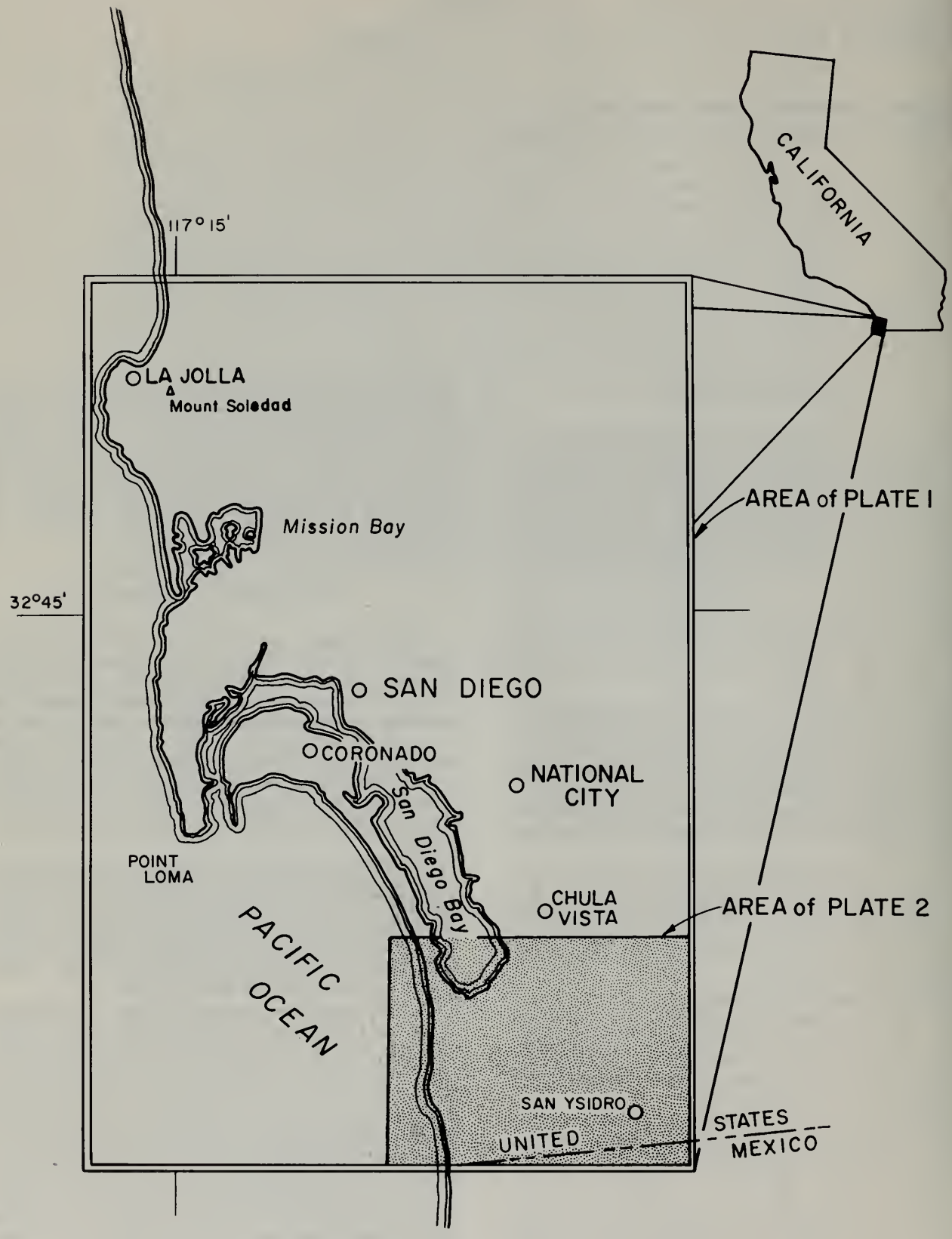


Figure 1. Index map showing the area of fault mapping (plate 1) and geophysical investigation (plate 2).

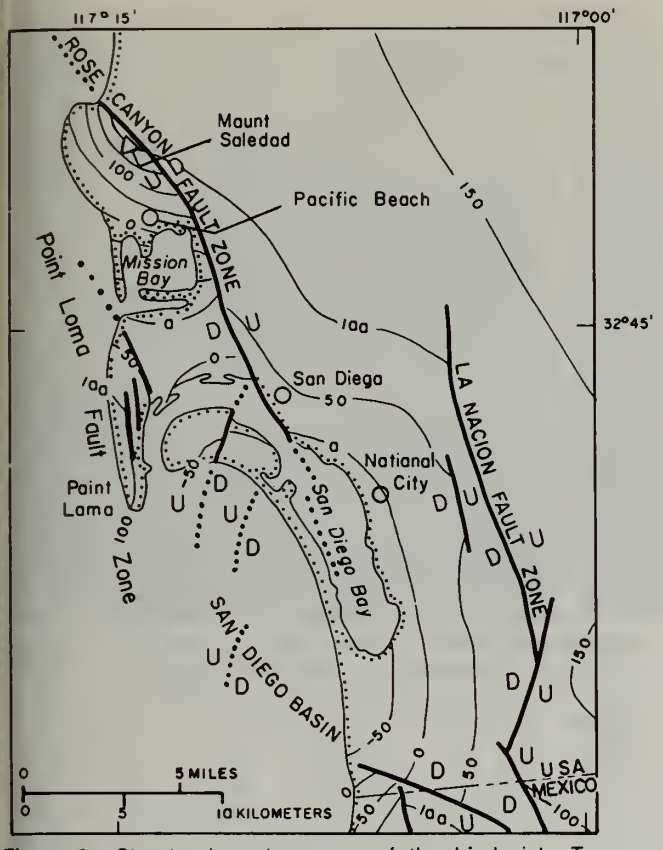


Figure 2. Structural contour map of the Lindavista Terrace showing tectonic deformation related to major faults, after Moore and Kennedy, 1975 . Contour interval 50 m; datum is mean sea level. (U, upthrown side; D, downdropped side.)

fault zone, is in excess of 100 m. North of San Diego Bay, in the vicinity of Mission Bay, the northernmost part of the graben occurs between the Rose Canyon and Point Loma fault zones. This part of the graben is the result of rotation of the Mount Soledad block along an axis that lies normal to the strike of the Rose Canyon fault zone. This rotation has elevated Mount Soledad along the northwest side of the zone and depressed Mission Bay along the southwest side (Peterson, 1970). The Quaternary age of this tilting is supported by geologic mapping (Kennedy, 1968) that shows the wave cut platform, upon which the Lindavista Formation rests, inclined to the south and extending nearly continuously from an elevation of over 250 m on Mount Soledad to near sea level at Pacific Beach (figure 2). This tilting, as well as steep folding in the northeastern part of the Mount Soledad block, is believed to be the result of compression developed by strike-slip movement on the Rose Canyon fault (Moore, 1972).

AGE OF FAULTING

The following criteria were used in assigning ages to fault movements, in determining the average rate of slip associated with each fault zone, and in determining the tectonic style of faulting within the area studied.

A maximum age of fault movement has been assigned to each of the faults mapped where the age of the youngest known strata faulted has been determined. A minimum age of displacement has also been assigned to faults where it has been possible to determine the age of the oldest overlying strata not faulted. The capital letters H, L, Q or T are assigned faults where rocks of Holocene, late Pleistocene, early Pleistocene and Tertiary or older age respectively are faulted. Lower case letters h, l, q or t are used where rocks of these same ages are not faulted. Where the maximum and minimum age of fault movement is known both symbols are given with the capital letter preceding the lower case letter (e.g., T/q). In this example rocks of Tertiary or older age would be faulted but rocks of early Pleistocene age would not be faulted. Unlabeled faults indicate that no age could be established for the fault movement. A key to the age of strata faulted and not faulted is summarized below and given in table form on plate 1.

Holocene sediments in the study area include alluvium, soil, slopewash and landslide debris. Only a few faults in the area are known to displace such sediments and are labeled (H).

The upper Pleistocene Bay Point Formation is offset by numerous faults. Because many of these faults are not overlain by younger sediments, only a maximum age of displacement can be established. These faults are labeled (L). Where Holocene strata overlap faults that offset the Bay Point Formation those faults are marked (L/h). The age of the Bay Point Formation has been given as approximately 1.2×10^5 years, based on uranium series ages of the contained coral *Balanophyllia elegans* (Ku and Kern, 1974).

The Lindavista Formation, which is approximately 10^6 years in age, is offset by many faults in the area studied. These faults are indicated by (Q). The age of the Lindavista Formation is based primarily on the presence of the extinct mollusk *Pecten bellus* and on its unconformable relationship with the underlying and more extensively deformed upper Pliocene San Diego Formation (G. L. Kennedy, 1973). Peterson (1970) has suggested a mid-Pleistocene age for the Lindavista Terrace, a wave-cut feature upon which the Lindavista Formation was deposited and in medial stratigraphic position between the higher Poway Terrace, considered to be early Pleistocene in age, and the late Pleistocene Nestor Terrace upon which the Bay Point Formation rests. For purposes of the present study, the more conservative early Pleistocene age is considered more acceptable because its age is based on a fossil fauna, although admittedly meager.

Tertiary and older rocks that have been faulted in the area include the Pliocene San Diego Formation, Miocene Otay Formation, Eocene Poway and La Jolla Groups, and Upper Cretaceous Rosario Group. Faults that offset these strata alone are marked (T) but where they are overlapped by strata of the Bay Point or Lindavista Formations they are labeled T/l or T/q respectively.

FAULTS INVESTIGATED

The following discussion is divided into parts dealing with (1) Rose Canyon fault zone, (2) Point Loma fault zone, (3) La Nacion fault zone, (4) San Ysidro fault zone, and (5) faults underlying the Tijuana flood plain, border hills area, and San Diego Bay.

Many exposures of fault offsets in the project area are illustrated by text figures (see locations on plate 1).

Rose Canyon Fault Zone

The Rose Canyon fault zone within the area mapped is locally more than 1 km wide and is composed of both dip-slip and strike-slip en echelon faults that together extend from La Jolla Cove on the north to San Diego Bay and beyond on the south (plate 1). The longest individual breaks within the zone include the Rose Canyon, Mount Soledad, Country Club, and Old Town faults. The regional strike of the fault zone at La Jolla is N.50°-60°W. (figures 3, 4, 5) whereas the strike to the south adjacent to Mission Bay and Old Town is more northerly by 20-30 degrees (figures 6, 7). The change in strike is gentle and occurs southeast of Mount Soledad in the vicinity of Rose Canyon. In addition to the predominant northwest striking faults are many sub-parallel shorter breaks that strike from a few degrees west of north (figure 8) to a few degrees east of north (figure 9). Displacements on these smaller faults are mostly dip-slip in nature and on the order of 1-5 m in extent.

At La Jolla, Upper Cretaceous rocks of the Point Loma Formation underlie the Mount Soledad block along the western side of the fault zone and are juxtaposed with Eocene strata of the Ardath Shale and Mount Soledad Formation along its east side. The western side of the fault zone is formed by the Country Club fault, which lies adjacent to the Pacific Beach syncline between La Jolla and Mission Bay (plate 1). The Country Club fault is exposed on the north facing slopes of Mount Soledad from near Romero Drive (figure 4) to the sea cliffs at La Jolla Cove. Rocks of Eocene age are downdropped to the west and juxtaposed with Upper Cretaceous strata along this segment of the fault zone. The late Pleistocene Bay Point Formation appears to overlap the fault without offset at both La Jolla and Pacific Beach, although sediments of the early Pleistocene Lindavista Formation are faulted. At latitude 32° 49' 19" N., longitude 117° 13' 54" W., along the southern part of the Country Club fault, strata of the Lindavista Formation are juxtaposed with Eocene rocks. The dip-slip component of faulting at this locality is approximately 30 m, with the younger rocks downdropped along its western side.

The eastern margin of the fault zone extends to the Rose Canyon, Mount Soledad and Old Town faults which can be traced from near La Jolla Cove on the north, for about 12 km south to, and alongside, San Diego Bay. In its southernmost exposures near Old Town, the Rose Canyon fault lies en echelon with the Old Town fault (plate 1). Adjacent to and west of these faults, strata of the Lindavista and San Diego Formations dip 10°-20° W. (figures 6, 7, 10, 11) and project beneath the northern end of the San Diego Bay.

In the central portion of the Rose Canyon fault zone, well records reported by Gray and others (1971) show the contact between Upper Cretaceous and Eocene rocks at a depth of approximately 900 m below mean sea level, whereas along the west side this contact crops out at approximately 30 m above mean sea level. Using an estimated dip of 2°-5° E. for the regional attitude of this contact, based on surface measurements, an average figure of 800 m of post Eocene dip-slip separation is suggested here with the west side of the fault uplifted with respect to the east side.

At Pacific Beach and Mission Bay the relative dip-slip separation along the eastern margin of the Rose Canyon fault zone is opposite that seen at La Jolla. Mission Bay is downfaulted along the western margin of the fault zone and is underlain by strata of the Lindavista Formation (figure 2). These same rocks crop out on the south facing slopes of Mount Soledad, in La Jolla, and have been elevated, along the Rose Canyon and subparallel en echelon faults, to almost 250 m above mean sea level (Kennedy, 1973). Using the wave cut platform upon which these deposits rest as a datum the difference in elevation is approximately 150 m across the fault zone between Mount Soledad and Clairemont Mesa. A 250 m difference in elevation of this surface also exists over a 4 km distance that extends from Mount Soledad to the flanks of Mission Bay as the result of rotation of the Mount Soledad block toward the south (figure 20). Uplift of Mount Soledad by rotation resulted from compression caused by strike-slip movement at the S-shaped bend in the fault zone near La Jolla (Moore, 1972). Approximately 1 km of right lateral strike-slip separation of the shoreline that now forms Point La Jolla is considered to postdate the deposition of the Lindavista Formation, based on the similar resistance to erosion that the rocks have on either side of the fault, and the present configuration and elevation of the coastline and Lindavista Terrace respectively (Moore and Kennedy, 1975). In addition, the San Diego Formation has been displaced 4 km right laterally along the Rose Canyon fault, between Tecolote Canyon and Pacific Beach, since late Pliocene time (Kennedy, 1968, 1973).

The upper Pleistocene Bay Point Formation is the youngest unit known to be offset by the Rose Canyon and Mount Soledad faults. The wave-cut terrace upon which these deposits rest is vertically offset more than 10 m at La Jolla Cove and is gently tilted downward to the south toward Mission Bay (Kennedy, 1975).

Although Holocene sediments are not known to be displaced by the Rose Canyon fault zone in the onshore part of the area, offshore subbottom acoustic profiles of the area between La Jolla and

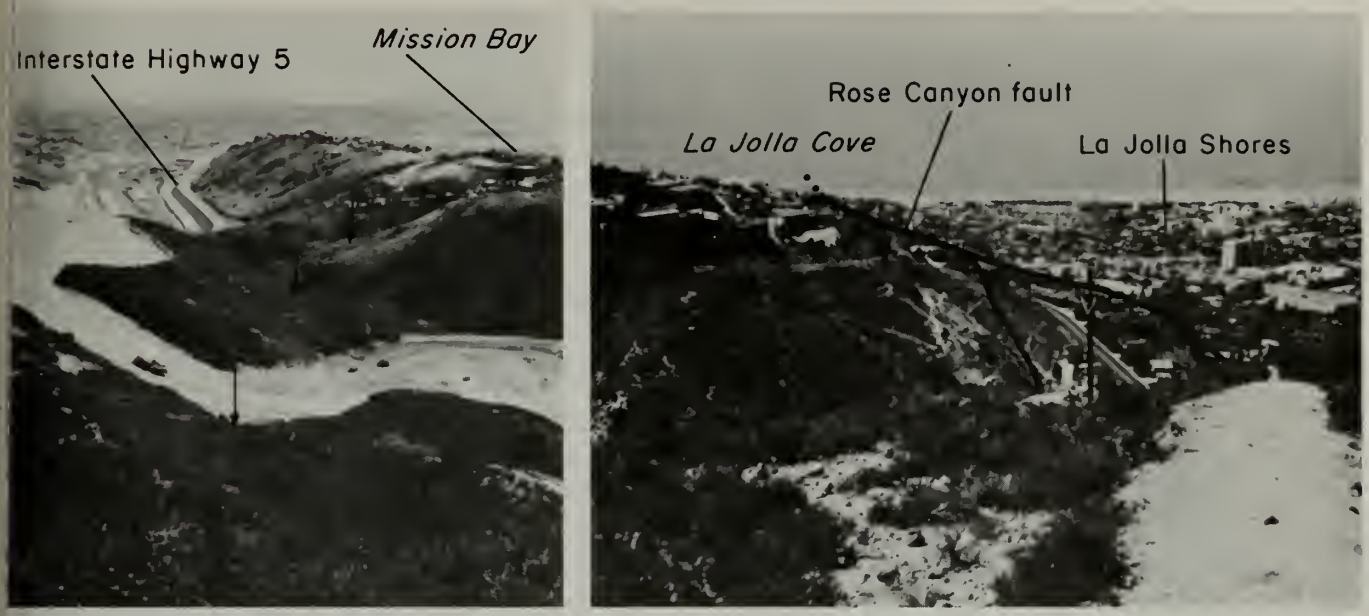


Figure 3. Fault line scarp of the Mount Soledad fault is marked by arrows. Left photograph, view southeast; right photograph, view northwest, both from Easter Cross on Mount Soledad. The fault strikes N. 50° W. and dips 80° E. (see plate 1 for location).

Figure 4. The Country Club fault, marked by arrows, lies within the Rose Canyon fault zone on Mount Soledad and juxtaposes strata of the Eocene Mount Soledad Formation (Tms) and Upper Cretaceous Cabrillo Formation (Kc). The youngest rocks known to be cut by this fault belong to the Pleistocene Lindavista Formation. The fault strikes N. 50° W. and dips 75° E. View east (see plate 1 for location).

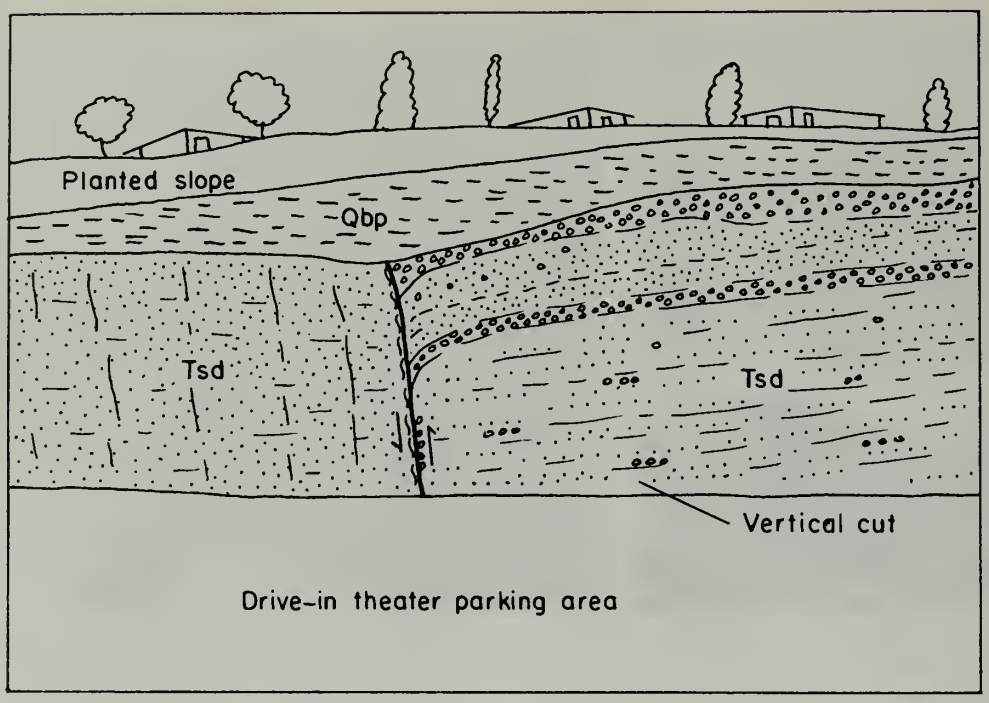


Figure 5. Conglomerate and sandstone facies of the San Diego Formation (Tsd) in fault contact with finer grained sandstone facies of the San Diego Formation. The slope is capped by a thin succession of late Pleistocene Bay Point Formation (Qbp) which has not been truncated by the fault. Strata of the Lindavista Formation are faulted immediately north of this exposure. The fault strikes N. 45° W. and dips 80° E. View north (see plate 1 for location).

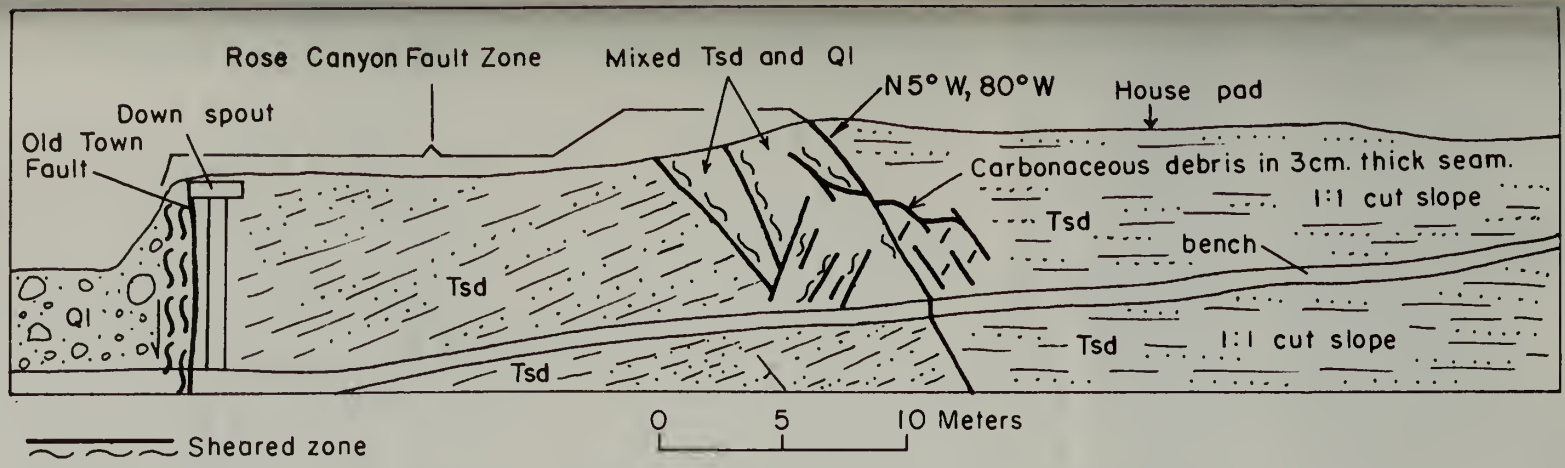


Figure 6. The Old Town fault here strikes N. 5° W. and dips 80° E. Rocks of the San Diego Formation (Tsd) lie to the east and within part of the fault zone and are juxtaposed with rocks of the Lindavista Formation (Ql). Bedding within the fault zone strikes N. 25° E. and dips 20° W. View north (see plate 1 for location).

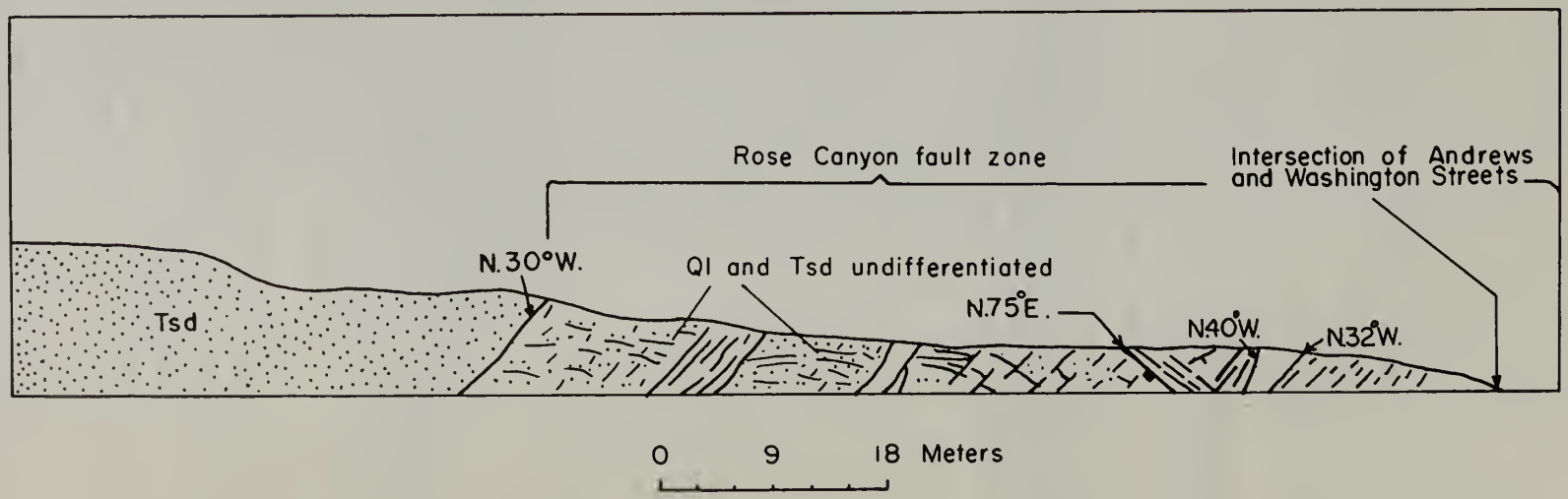


Figure 7. Rose Canyon fault zone juxtaposes strata of the upper Pliocene San Diego Formation (Tsd) and lower Pleistocene Lindavista Formation (Ql). The fault zone here is approximately 70 m wide and the strike is N. 35° W. View south (see plate 1 for location).

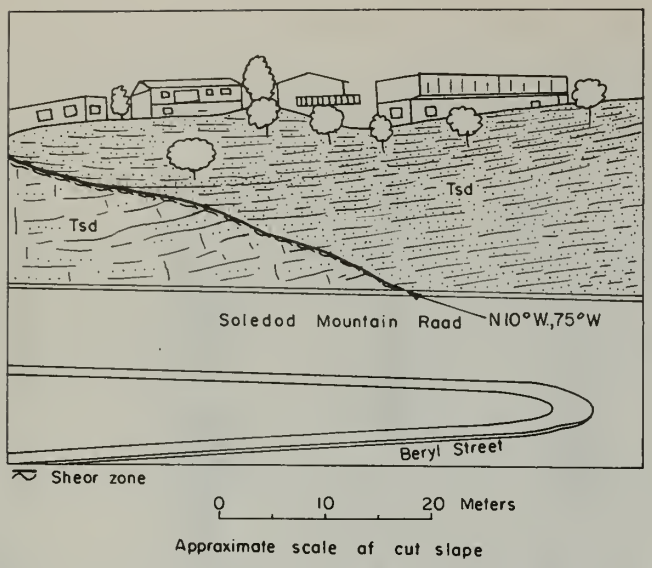


Figure 8. Fine-grained sandstone of the Pliocene San Diego Formation (Tsd) in fault contact with a sandstone and siltstone facies also of the San Diego Formation. The fault strikes N. 5°-10° W. and dips 75° W. The sandstone and siltstone facies, southeast side of the fault, appears to be elevated with respect to the rocks on the northwest side. View east (see plate 1 for location).

Figure 10. Inclined Pleistocene rocks of the Lindavista Forma tion dip 20 degrees to the west. They lie adjacent to the Rose Ca nyon fault zone here and project beneath the northern end of Sa Diego Bay (see plate 1 for location).

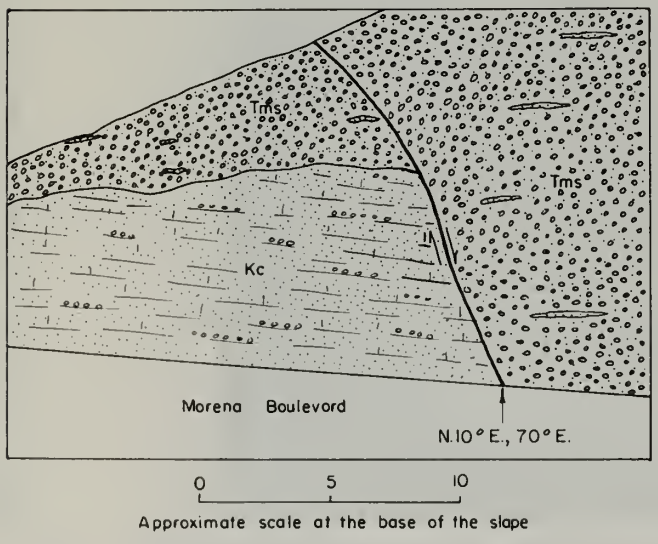


Figure 9. Small fault within the Rose Canyon fault zone strikes N. 10° E. and juxtaposes rocks of the Upper Cretaceous Cabrillo Formation (Kc) and the conglomeratic part of the Eocene Mount Soledad Formation (Tms). No Quaternary rocks occur along this part of the fault zone. View east (see plate 1 for location).

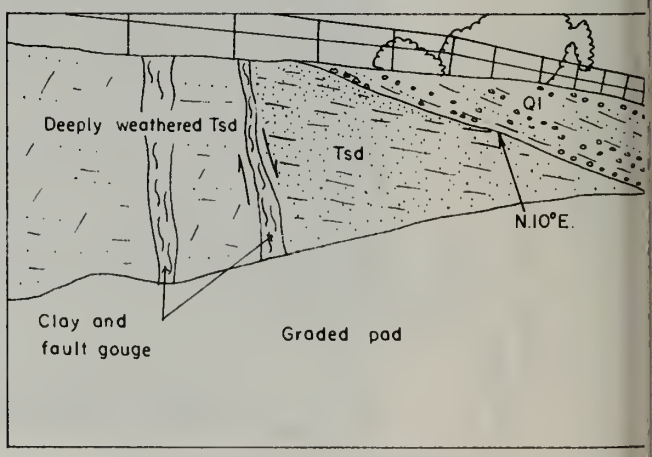


Figure 11. Faulted strata of the San Diego Formation (Tsd) an Lindavista Formation (Ql) are juxtaposed and tilted approximatel 10 degrees west. View south (see plate 1 for location).

Oceanside, and of the San Diego Bay and immediate offshore shelf areas south of Point Loma, show that sediments of probable Holocene age on the sea floor are displaced by faults that appear to be related to this zone (Moore, 1972; Moore and Kennedy, 1975).

By comparing the relative amounts of fault displacements with the ages of the strata faulted, we can reconstruct a long history of faulting probably postdating the age of the middle Eocene La Jolla Group (approximately 50 m.y.) or possibly the middle Miocene Otay Formation (approximately 10 m.y.) and predating the age of the upper Pliocene San Diego Formation (approximately 2 m.y.). Assuming that the 800 m of vertical separation revealed by well data occurred in the past 50 m.y., 150 m in the past 1 m.y., and 10 m in the past 100,000 years as postulated above, an average rate of dip-slip faulting for this period is between 10 and 15 cm/10^3 years. The average rate of strike-slip fault movement based on offsets of the upper Pliocene San Diego Formation and the shoreline at Point La Jolla is 1-2 m/10^3 years.

Point Loma Fault Zone

The Point Loma and Fort Rosecrans faults strike north to northwest and together as a zone extend from the southwestern part of Mission Bay south to Fort Rosecrans (plate 1). Rocks of the upper Pleistocene Bay Point Formation and lower Pleistocene Lindavista Formation are juxtaposed with Eocene strata along the Point Loma fault, and with Upper Cretaceous strata along the Fort Rosecrans fault (figures 12, 13, 14, 15).

The primary component of fault movement along the Point Loma fault zone is dip-slip. At the northernmost exposures of the zone the Bay Point Formation is downdropped approximately 20 m (figure 12). At Fort Rosecrans near the southernmost exposures of the zone, in the sea cliffs south of Ballast Point the Bay Point Formation is downdropped approximately 5 m (figure 13). Kern (1973) has documented 12 m of vertical separation along the bay shore side of Point Loma for the past 125,000 years based on fault offsets of the wave cut platform (Nestor Terrace) upon which the Bay Point Formation rests.

In the central part of the peninsula, westward from Ballast Point, strata of the Lindavista Formation are downdropped progressively on the order of 100 m by several step faults (figure 15, plate 1). These faults together form the western margin of a graben that underlies San Diego Bay. The extent to which strata of the Lindavista Formation are faulted within the central part of the graben is unknown; however, based on the presence of a restricted Pleistocene fossil gastropod, *Turritella gonostoma,* from a bore hole drilled near the middle of San Diego Bay beneath the Coronado Bridge at a depth of 50 m (W.J. Zinsmeister, written communication) we are certain that the total vertical separation, of Pleistocene strata, from the crest of the Point Loma Peninsula to central San Diego Bay is in excess of 150 m. An average rate of vertical faulting of between 10 and 15 cm/10^3 years is suggested for the Point Loma fault zone, based on the age and extent of the faulted strata.

La Nacion Fault Zone

The La Nacion fault zone has a regional trend striking northwesterly, subparallel to the Rose Canyon and Point Loma fault zones (plate 1). Some of the individual faults within the zone, however, strike northeast. The zone is composed primarily of a large number of en echelon faults that are mostly Quaternary in age and dip-slip in nature. The largest of these are the La Nacion, Sweetwater, Murphy Canyon, and Mission Gorge faults.

North of Mission Valley, in Mission Gorge and Murphy Canyon, two inconspicuous Quaternary faults constitute what we consider the northernmost part of the La Nacion fault zone. The Murphy Canyon fault offsets the base of the Lindavista Formation, approximately 10 m down to the east (figure 16). The Mission Gorge fault also displaces strata of the Lindavista Formation down to the east but on the order of 25 m. Both faults are overlain by thick deposits of Holocene alluvium making their locations somewhat uncertain.

South of Mission Valley in the vicinity of Collwood Boulevard, the La Nacion fault is well exposed (figure 17). It cuts the lower Pleistocene Lindavista Formation and is overlain by apparently unfaulted Holocene soil. South, between University Avenue and Imperial Highway, good stream wall exposures show that the La Nacion fault is 1-2 m wide (figure 18). Strata of Quaternary and Tertiary age are downdropped to the west and juxtaposed with older rocks along this segment of the fault. The Quaternary deposits are nonmarine sandstone deposited on a surface having up to 10 m of relief. These deposits were apparently laid down after the Pleistocene transgressive marine planation of the Lindavista Terrace and the deposition of the Lindavista terrace materials (Lindavista Formation), as slopewash and fluviatile debris. Channels, poorly sorted sandstone and conglomerate, prominent cross bedding and organic debris, including bone and wood fragments, characterize this facies and suggest a nonmarine origin. Because of their close relationship to the Lindavista Formation and probable similar age, these deposits are considered part of the Lindavista Formation for the purposes of this study.

From Imperial Avenue south to the town of Bonita, the La Nacion and Sweetwater faults together form a broad and multi-branched zone that is locally up to 1 km wide (plate 1; figures 19, 20, 21, 22, 23, 24, 25). Approximately 70 m of vertical separation have occurred with respect to the Lindavista Formation since early Pleistocene time, as seen at Imperial Avenue on the La Nacion fault, and at Sweetwater River on the Sweetwater fault. South of Bonita and Sweetwater Valley, the Sweetwater fault gradually dies out and the major proportion of displacement within the zone is associated with the La Nacion fault. Between the town of Bonita and

Figure 12. Trace of the Point Loma fault (marked by arrows), which juxtaposes strata of the Bay Point and Mount Soledad Formations. View northeast (see plate 1 for location).

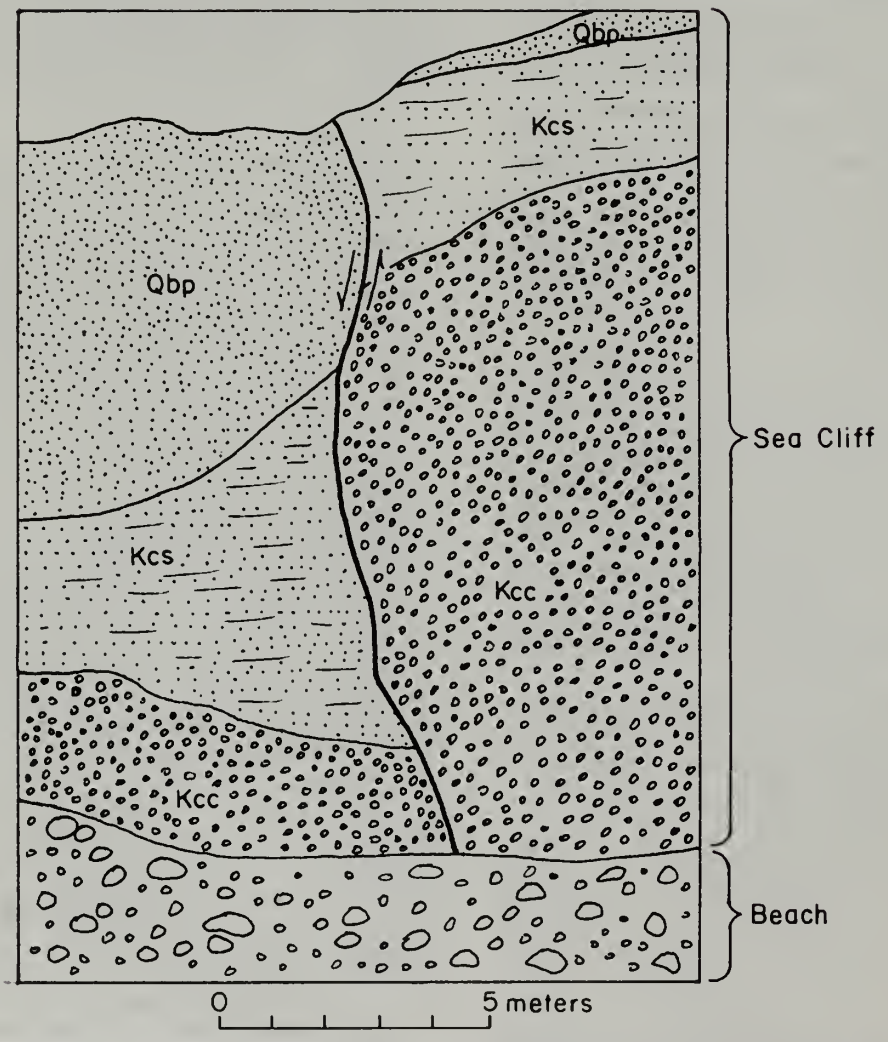


Figure 13. A dip-slip separation of 5 m occurs here, with respect to the base of the Bay Point Formation (Qbp). Faulting juxtaposes strata of the Upper Cretaceous Cabrillo Formation (Kcc, conglomerate part; Kcs, sandstone part) with the poorly consolidated sediments of the Bay Point Formation. View west (see plate 1 for location).

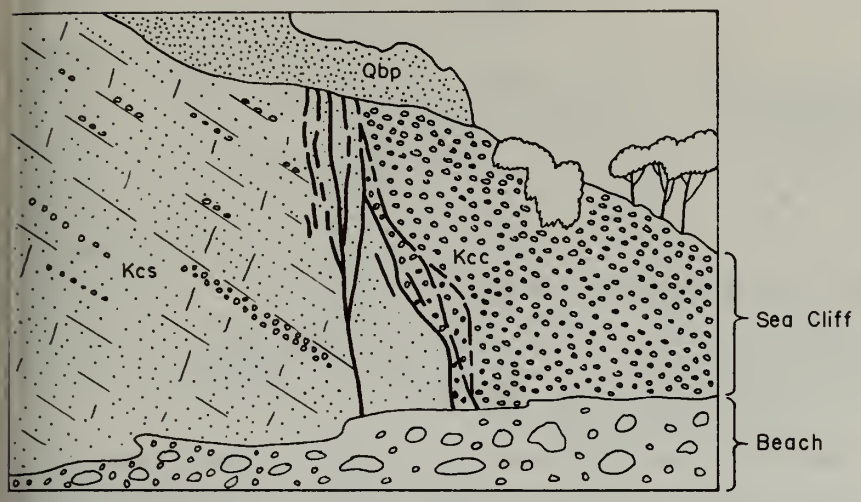


Figure 14. This fault, part of the Fort Rosecrans fault, approximately 1 m wide, juxtaposes Upper Cretaceous strata of the Cabrillo Formation (Kcc, conglomerate part; Kcs, sandstone part). The Bay Point Formation laps the fault at this location. The fault strikes N. 15°-20° W. dips 65° E. The east side is downdropped with respect to the west side. The sea cliff is about 25 feet high. View northwest (see plate 1 for location).

Figure 15. The Fort Rosecrans fault juxtaposes strata of the Lindavista and Cabrillo Formations. The Lindavista Formation is downdropped toward San Diego Bay (right). Arrows indicate the position of the fault in steep natural exposures. View north (see plate 1 for location).

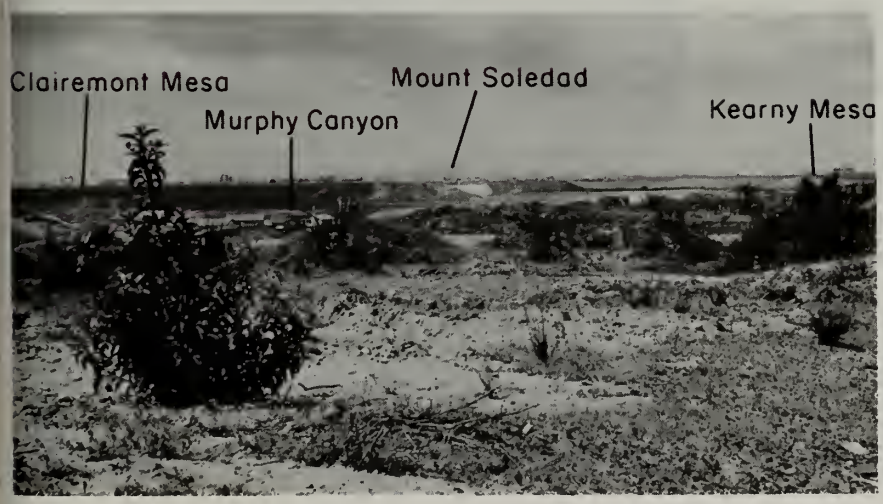


Figure 16. The elevated surface of the Lindavista Terrace along the west side of the Murphy Canyon fault. Mount Soledad, capped by the Lindavista Formation, has been elevated in Quaternary time by the Rose Canyon fault. View west (see plate 1 for location).

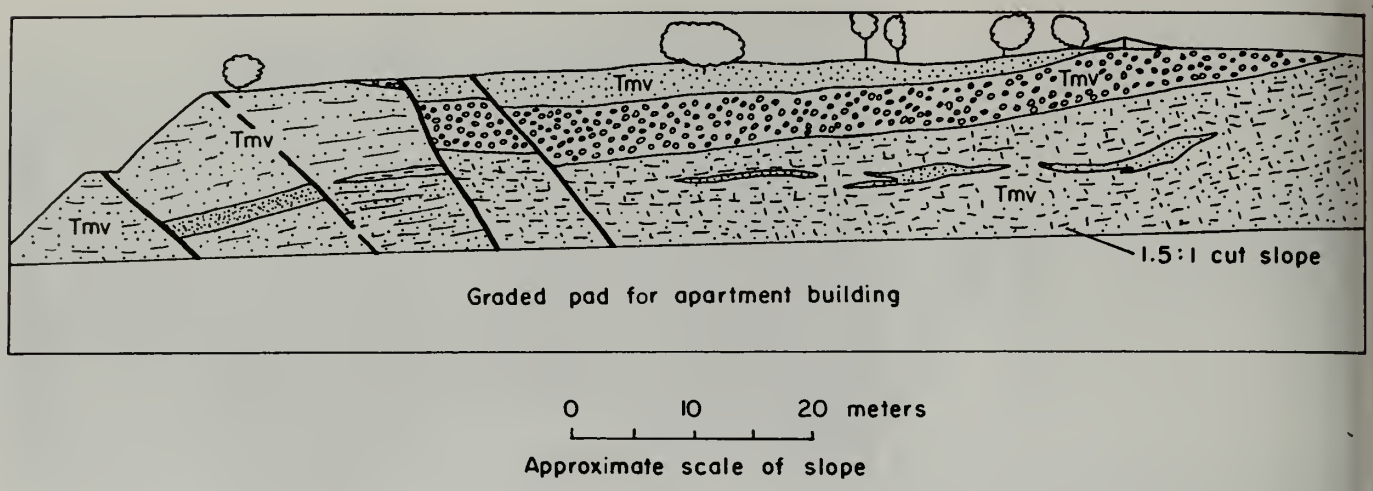


Figure 17. The La Nacion fault offsets strata of the Eocene Mission Valley Formation (Tmv). The Pleistocene Lindavista Formation is faulted by these same branch faults immediately south of this exposure. These are but a few of the small faults that constitute the northern end of the La Nacion fault in an area where the main trace of the fault is splaying into many parts. View north (see plate 1 for location).

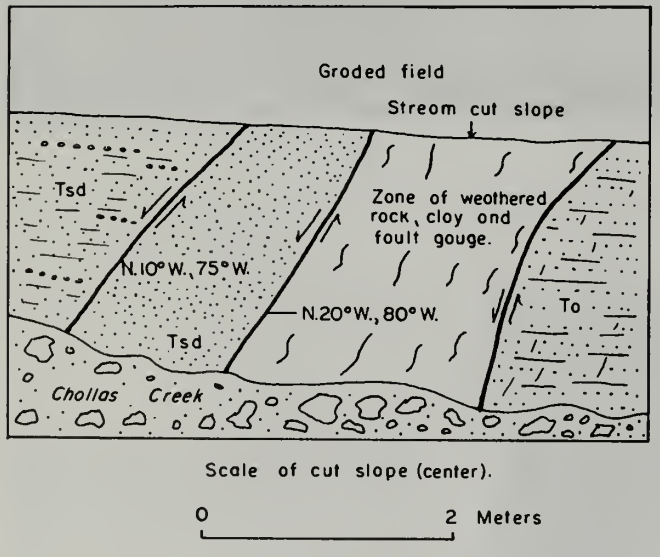


Figure 18. Rocks of the San Diego Formation (Tsd) downfaulted to the west (left) against rocks of the Otay Formation (To) along the La Nacion fault. View from Imperial Avenue where the curb and street are cracked. This cracking is considered to have resulted from settling within the fault zone rather than from direct tectonic origin. The same faults can be seen immediately north of this view in railroad cut. The fault zone within this area strikes N. 20° W., and dips to the W. 80°. View north (see plate 1 for location).

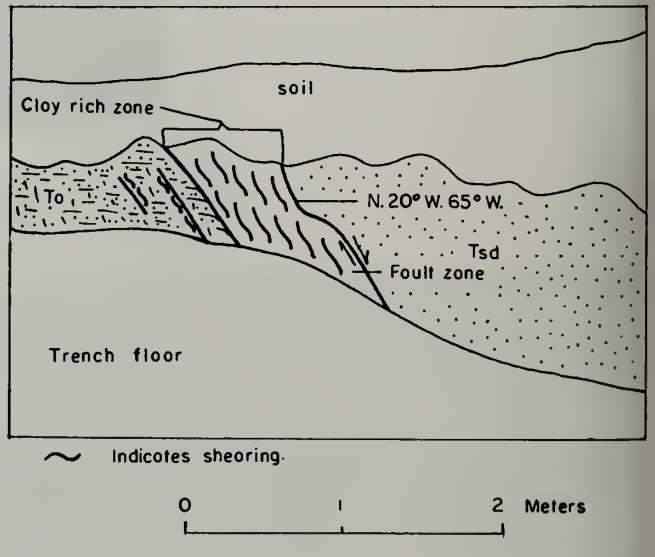


Figure 19. This fault lies within the La Nacion fault zone and juxtaposes rocks of the San Diego Formation (Tsd) and Otay Formation (To). A 1 m wide clay zone, containing numerous shears, is altered and deeply weathered material derived from the Otay Formation. The clay is montmorillonite and expansive. The top soil is not faulted but appears to have slumped into or to have been deposited along an old fault scarp. View south (see plate 1 for location).

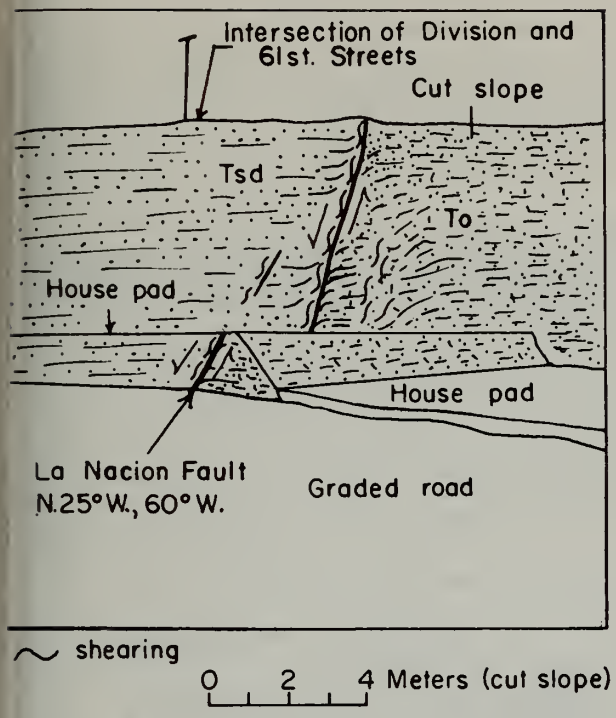


Figure 20. The La Nacion fault exposed in a newly graded housing development just south of the intersection between Division and 61st Streets. The San Diego Formation (Tsd) is downdropped to the west (left) and faulted against rocks of the Otay Formation (To). Rocks of the lower Pleistocene Lindavista Formation are faulted immediately north of this exposure. The vertical separation here since late Pliocene time is in excess of 75 m. View north (see plate 1 for location).

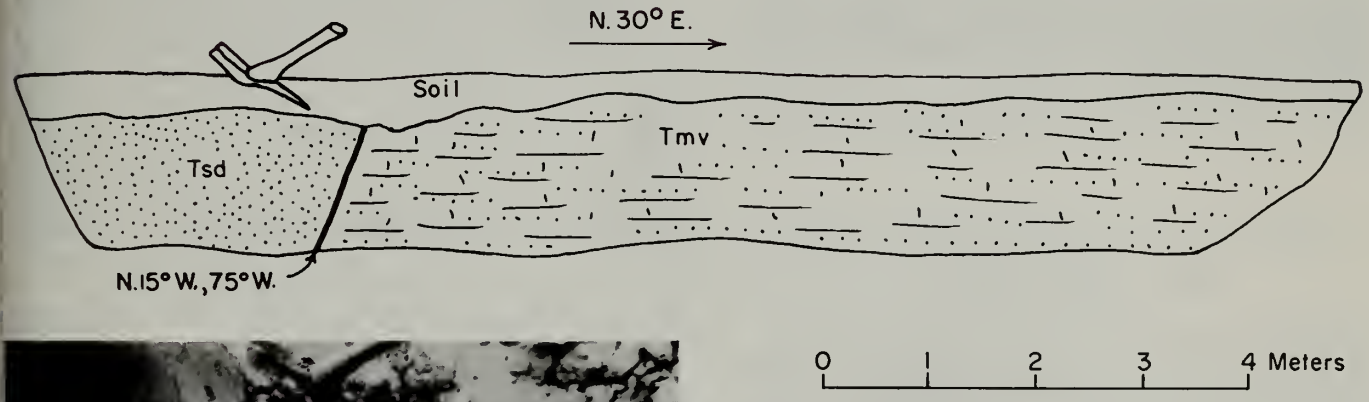


Figure 21. The La Nacion fault zone here juxtaposes rocks of the San Diego Formation (Tsd) and Otay Formation (To). The soil is not faulted. View northwest (see plate 1 for location).

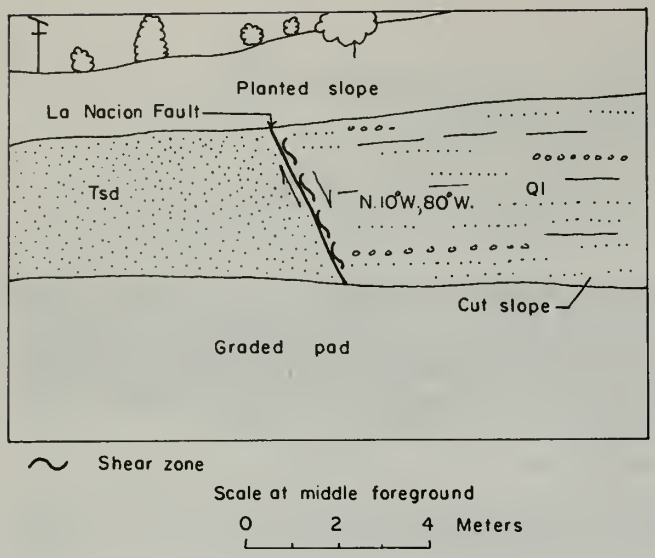
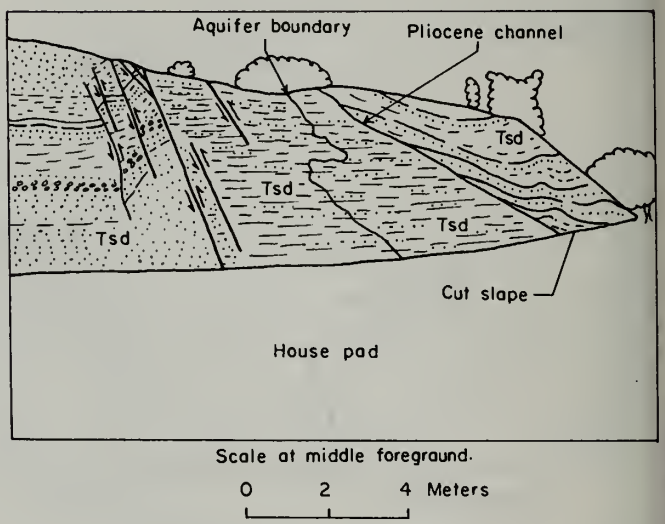


Figure 22. Branch of the La Nacion fault juxtaposes rocks of the San Diego Formation (Tsd) with lower Pleistocene deposits (Ql). The fault strikes N. 10° W. and dips 80° W. View south (see plate 1 for location).

Figure 23. La Nacion fault zone juxtaposes rocks of the San Diego Formation (Tsd). Combined dip-slip separation of these faults is approximately 10 m. Rocks of early Pleistocene age are offset by these faults immediately north of this slope. View north (see plate 1 for location).



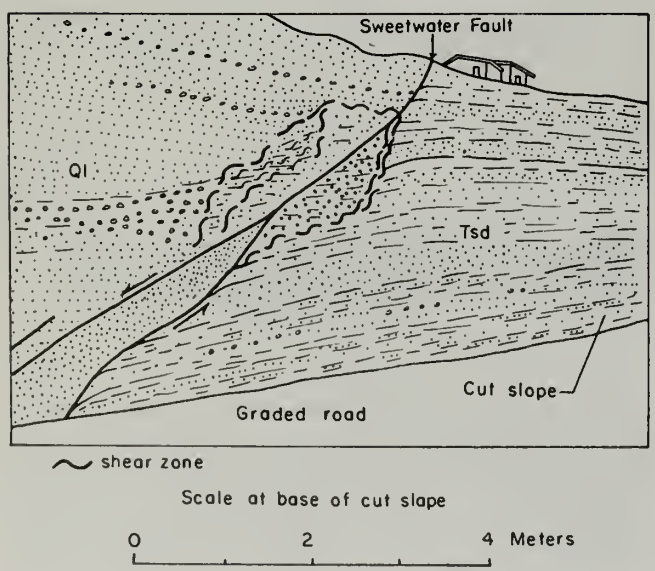


Figure 24. Lower Pleistocene strata of the Lindavista Formation (Ql) lie in fault contact with rocks of the San Diego Formation (Tsd). The Sweetwater fault at this location has several branches all displaying dip-slip separation. The total amount of separation here is in excess of 35 m. View north (see plate 1 for location).

Telegraph Canyon, the La Nacion fault is well exposed in exploratory excavations (figures 26, 27, 28, 29, 30). Within this segment of the fault, the vertical separation of the upper Pliocene San Diego Formation is approximately 75 m (figure 27), whereas that of the Lindavista Formation is approximately 18 m (figure 29).

Between Telegraph Canyon and Poggi Canyon, the strike of the La Nacion fault changes from N.25° W. to N.5°-10° E. (plate 1). Good exposures of the fault are seen immediately north of this bend near Telegraph Canyon in an exploratory trench (figure 31) and in a road cut for Telegraph Canyon Road (figure 32). At Poggi Canyon, south of the change in strike, the fault is again well exposed in a cut slope (figure 33). The vertical separation between Poggi and Telegraph Canyons across the fault is down to the west and approximately 75 m with respect to the Lindavista Formation and at least 125 m with respect to the San Diego Formation.

South of Poggi Canyon adjacent to and within Otay Valley the La Nacion fault is covered by unfaulted Holocene soil and alluvium (Hart, 1974). Within this area the strike of the fault changes from N.5° E. to approximately N.50° E. Three exploratory trenches cut on the south side of Otay Valley (figures 34, 35, 36) exposed the La Nacion fault and confirmed the persistence of the N.50° E. trend for a distance of nearly 1 km. This change in strike is possibly related to prominent east-west faults that intersect the La Nacion fault within and south of Otay Valley (plate 1). Six exploratory trenches were cut, exposing the fault immediately north and south of this change in strike (figures 35, 36, 37, 38, 39, 40), but they did not reveal an age relationship between the east-west and north-south oriented segments. One km south of Otay Valley, the trend of the fault resumes a more northerly direction, parallel to its strike north of the Valley (figures 38, 39).

Between Otay Valley and the southern termination of the La Nacion fault at San Ysidro, the dip-slip separation based on the difference in elevation of the essentially horizontal contact between the San Diego and Lindavista Formations across the fault is approximately 100 m. The maximum age for this displacement is early Pleistocene, although terrace deposits that may be younger than the Lindavista Formation are faulted (figures 35, 38, 40).

San Ysidro Fault Zone

The San Ysidro fault zone is composed of a number of en echelon Quaternary faults exposed in the southeast portion of the project area, extending from the U.S.-Mexican boundary on the south about 7 km to Palm City on the north (figures 41, 42, 43). These faults have an average strike of N.40°-50° W. and lie subparallel to the regional strike of faulting. The displacements associated with the San Ysidro fault zone north of Otay Mesa Road are dip-slip in nature, west side downdropped, and display from 2 to 5 m of vertical separation. Strata of the early Pleistocene Lindavista Formation are juxtaposed with Tertiary rocks of the San Diego and Otay Formations in this area. Strong lineaments seen in air photos of the vicinity of Palm City suggest a Holocene or late Pleistocene age of fault activity and are the primary criteria for extending the fault north of Otay Mesa Road.

Along the southern part of the San Ysidro fault zone, immediately east of San Ysidro, the San Ysidro fault has juxtaposed the Lindavista, San Diego and Otay Formations. Predominant movement between these strata is down to the west; this type of offset is associated with the fault from the U.S.-Mexican border to a point approximately 3 km to the north. The vertical separation along this fault segment is in excess of 30 m with respect to the base of the Lindavista Formation and 50 m with respect to the contact between the San Diego and Otay Formations.

Faults post-dating the age of the Lindavista Formation also lie within a few hundred meters east of and subparallel to the San Ysidro fault. Together these faults have displaced strata of the Lindavista Formation, down to the west, a minimum of 3-4 m. The age of the most recent activity along the San Ysidro fault zone is somewhat questionable, although we can assign to it a maximum age of early Pleistocene based on the faulted Lindavista Formation. Strong geomorphic lineaments associated with the fault are seen in Holocene(?) landslide debris near San Ysidro (Foster, 1973) and in Holocene or late Pleistocene slopewash near Palm City; these lineaments might suggest that moderately recent movements are associated with these faults.

Faults Underlying the Tijuana Valley and San Diego Bay

The Tijuana Valley, which trends westerly across the southern end of the study area (plate 1), appears to be structurally controlled and complexly dissected by faults of Quaternary age. Two prominent directions of faulting occur, one of which lies parallel to the northwest regional structural grain and the other nearly normal to it. The east side of the area is bounded by the San Ysidro fault, which steps Tertiary and Quaternary strata down along its southwest side toward the valley floor. The south side of the valley is bounded by a group of faults that are well exposed in the low-lying hills adjacent to the U.S.-Mexican border (figure 44, plate 1), herein referred to as "the border hills." These faults also step strata of Quaternary and Tertiary age down toward the valley floor, although in this area the downdropped side is to the northeast.

Holocene sediments of the Tijuana River Valley overlap many of the faults between the border hills area and the San Ysidro fault. The projection of faults beneath the deeply alluviated valley is therefore speculative. A geophysical investigation of this area has revealed the location and trend of

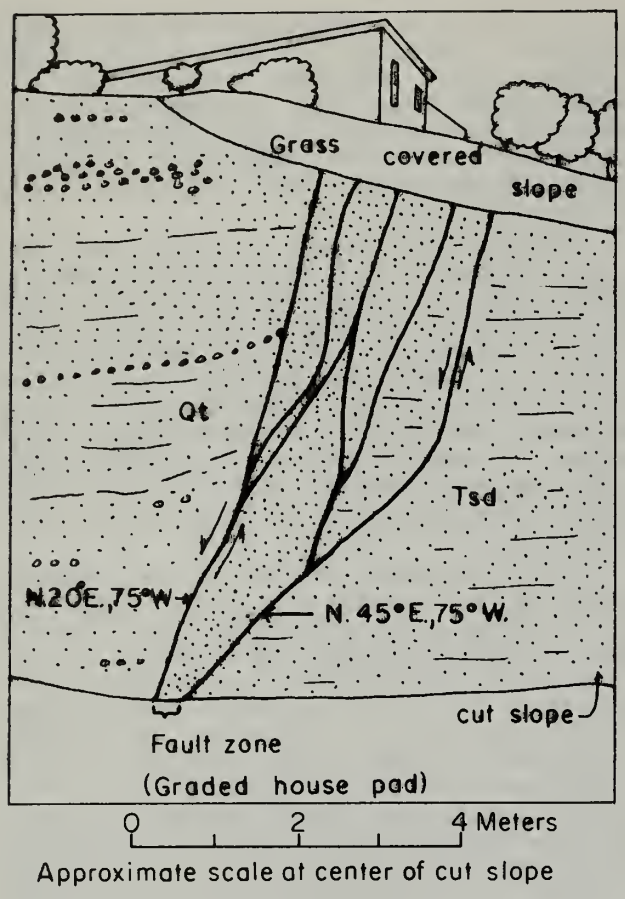


Figure 25. Multibranched segments of the Sweetwater fault juxtapose lower Pleistocene sediments (Qt) with upper Pliocene rocks of the San Diego Formation (Tsd). View north (see plate 1 for location).

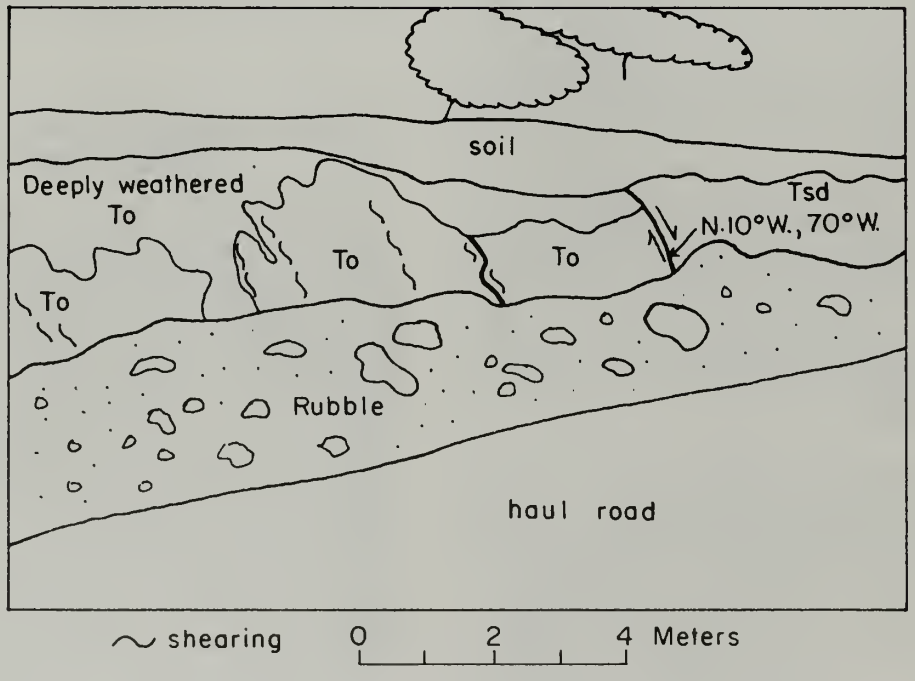


Figure 26. Rocks of the San Diego Formation (Tsd) lie in fault contact with deeply weathered sandstone beds of the Otay Formation (To). The weathered zone is predominantly caliche and clay. Soil and cobbles intermixed with the upper part of this zone are interpreted as Pleistocene ? soil or slopewash. The westernmost faults exposed strike approximately N. 10° W. and dip 70° W. The rubble is talus from the cut slope. View south (see plate 1 for location).

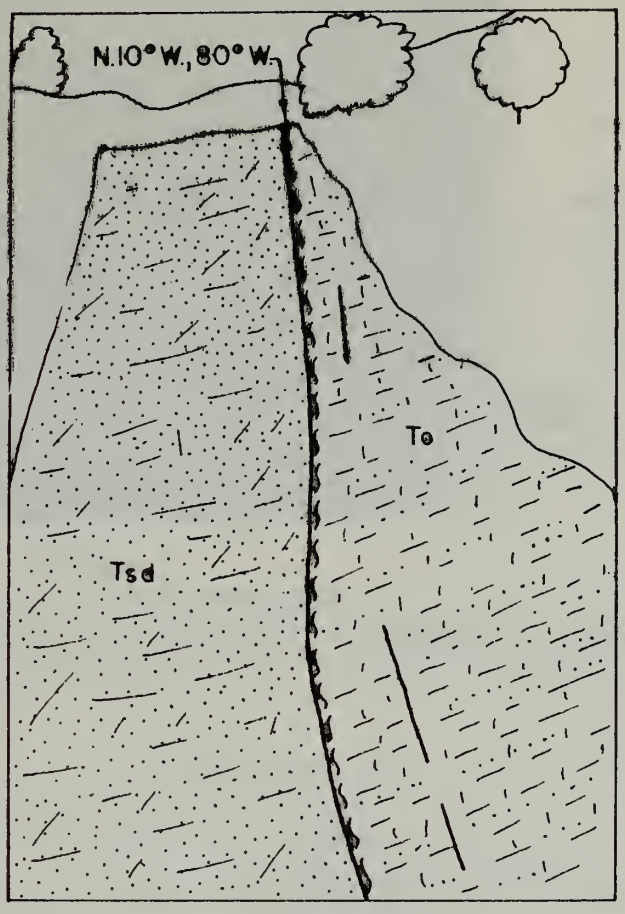


Figure 27. The La Nacion fault in floor of bulldozer excavation. The fault strikes N. 10° W. and dips 80° W. Rocks of the San Diego Formation (Tsd) are faulted down against rocks of the Otay Formation (To). The dip-slip separation measured on upper Pliocene strata is in excess of 75 m. Pleistocene rocks of the Lindavista Formation are not exposed here but are displaced by this fault less than 1 km to the south. View north (see plate 1 for location).

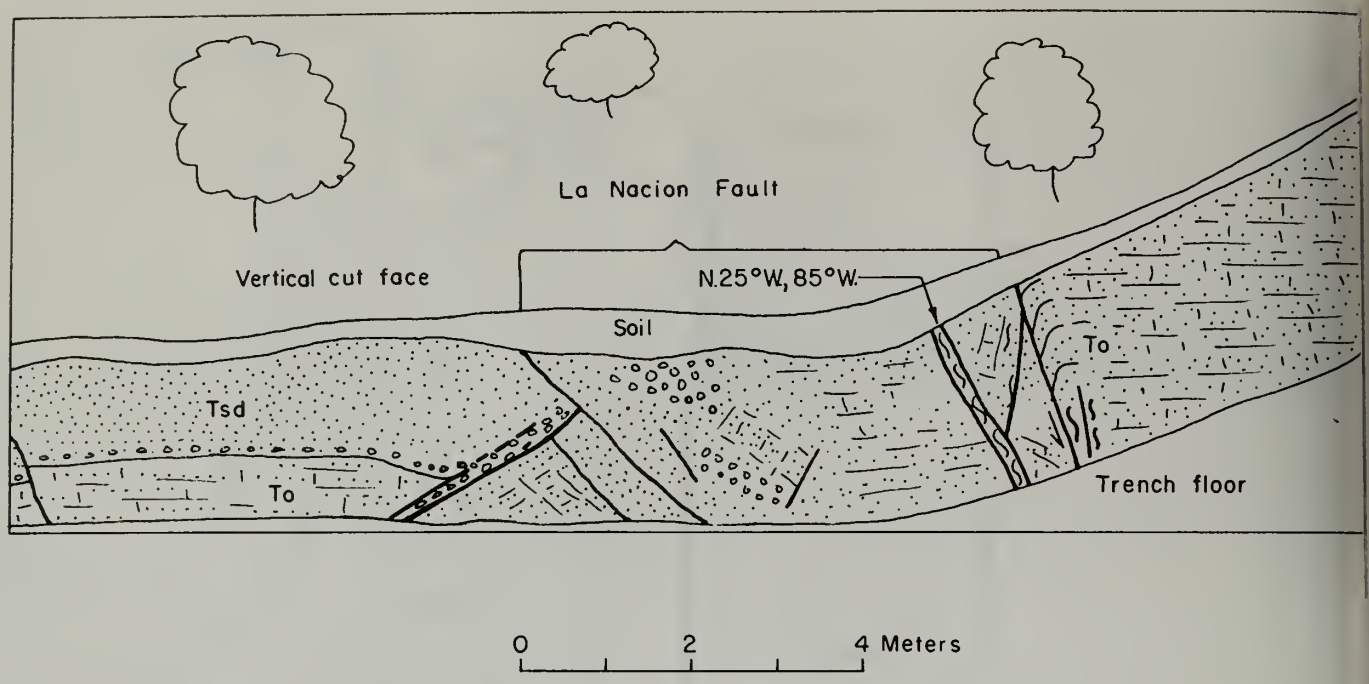


Figure 28. The La Nacion fault offsets the contact between the San Diego Formation (Tsd) and Otay Formation (To) approximately 7 m. The west side of the fault is down with respect to the east. View north in exploratory trench (see plate 1 for location).

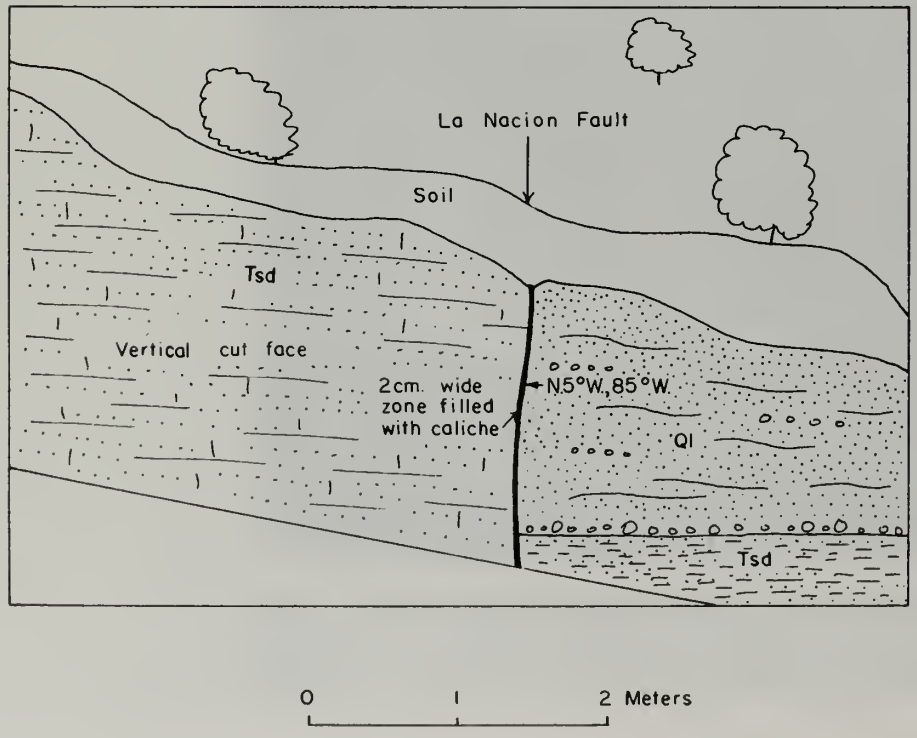


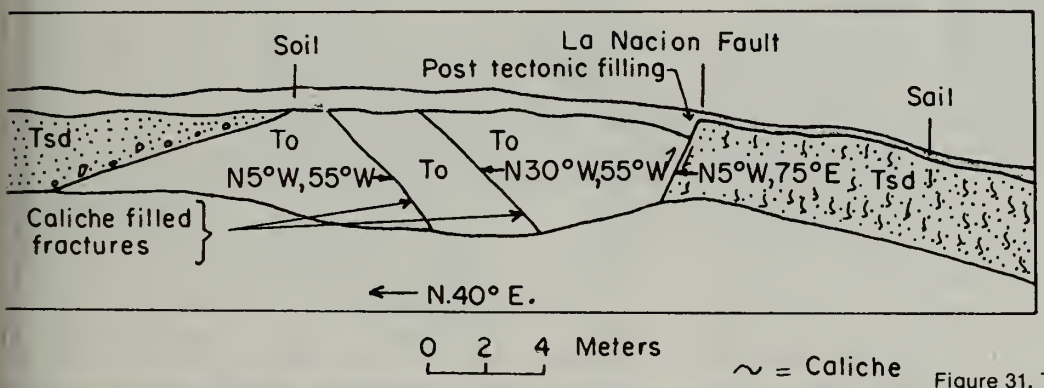
Figure 29. One of the faults within the La Nacion fault zone juxtaposes rocks of the San Diego Formation (Tsd) and Lindavista Formation (Ql). The dip-slip separation here has been 18 m since early Pleistocene time based on the net difference in elevation of the planar and horizontal base of the Lindavista Formation. The fault exposed in exploratory trench strikes N. 5° W. and dips 85° W. The zone of faulting is approximately 2 cm in width and no gouge is present. The fault surface is coated with caliche. Soil has been deposited in the upper 10 cm of fault zone but is not cut by the fault. View south (see plate 1 for location).

FAULT

U
D 75

(U, *upthrown*; D, *downdropped*)

Figure 30. The La Nacion fault at Telegraph Canyon is offset or terminated by northeast striking faults (plate 1). Strata of the Tertiary Otay (To) and San Diego Formation (Tsd) are juxtaposed here. A thin cap of Lindavista Formation (Q1) is also faulted in this vicinity approximately 18 m. Air view northeast (see plate 1 for location).



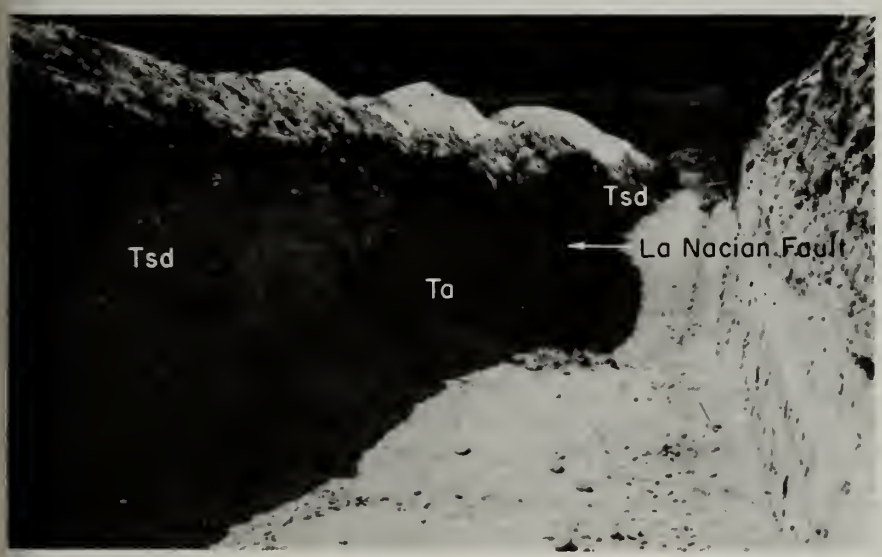


Figure 31. The La Nacion fault juxtaposes the San Diego Formation (Tsd) and Otay Formation (To). The fault strikes N. 5° W. and dips 75° E. The soil zone is not faulted but is thicker on the softer Otay Formation, probably as a result of (1) in situ soil development being more rapid in the Otay Formation than in the San Diego Formation, (2) the down slope migration of soil, and (3) infilling along an erosional fault scarp. The two small fractures within the Otay Formation show little or no displacement. They are filled with caliche which extends from the soil horizon, through expansion cracks, down into the bedrock. The San Diego Formation on the south side of the fault is deeply dissected by small caliche-filled fissures. The photograph shows the La Nacion fault on the opposite wall of the trench shown in sketch drawing. View looking east (see plate 1 for location).

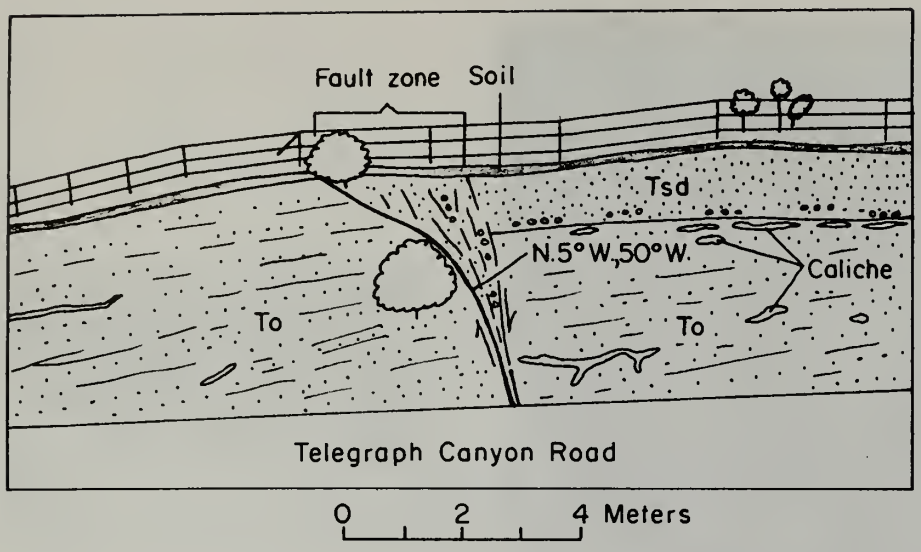
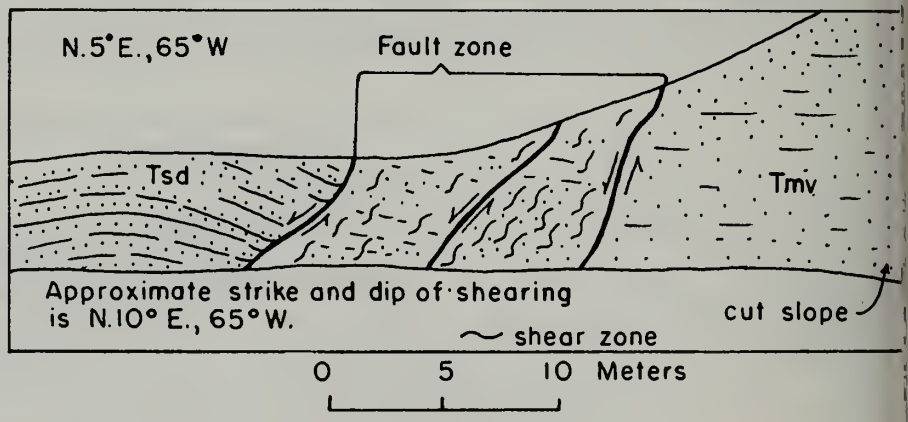


Figure 32. The La Nacion fault juxtaposes the San Diego Formation (Tsd) and the Otay Formation (To). Rocks within the fault zone are lithologically similar to those on the west side of the fault in the San Diego Formation. The fault strikes N. 5° W. and dips 50° W. The soil horizon that caps this cut along Telegraph Canyon Road is not displaced by the fault. The vertical separation measured is dip-slip in nature and on the order of 10 m in extent. View looking south (see plate 1 for location).

Figure 33. Rocks of the San Diego Formation (Tsd) are downdropped on the west (left) and faulted against rocks of the Mission Valley Formation (Tmv). Immediately north of this area the Pleistocene Lindavista Formation is offset about 10 m. The maximum separation here is dip-slip in nature and on the order of 50 m since late Pliocene time. View north at Poggi Canyon (see plate 1 for location).



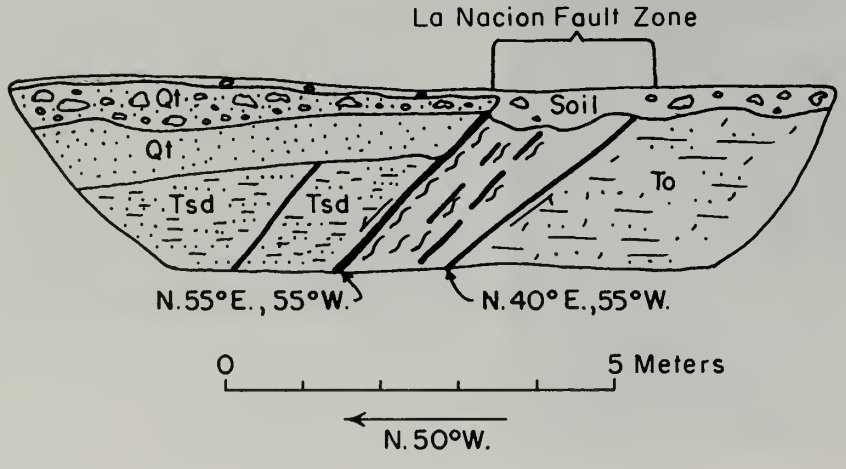


Figure 34. La Nacion fault zone, where Pleistocene nonmarine terrace deposits (Qt) and strata of the Pliocene San Diego Formation (Tsd) are juxtaposed with rocks of the Miocene Otay Formation (To). The soil overlying the Otay Formation is thicker than that overlying the Pleistocene terrace deposits but is not faulted. View north in exploratory trench (see plate 1 for location).

everal lineaments that are considered to be ossible faults (plates 1 and 2).

The area immediately north and offshore from he mouth of the Tijuana River Valley was in-estigated by shipboard marine geophysical echniques. Faults mapped during the course of that tudy are reported by Moore and Kennedy 1975). The largest of these faults are also shown on late 1 of this report. Moderately low angle dip-slip aulting characterizes the structure beneath San Diego Bay and offshore bight. These faults for the nost part strike from a few degrees west to a few legrees east of north, with dip-slip offset down to he east. The direction of slip is similar to that map-ped in the adjacent onshore area at Point Loma and he border hills adjacent to the Tijuana Valley. In contrast, the dip-slip faults mapped between Pacific Beach and Chula Vista have dip-slip movement down to the west. This fault pattern suggests that San Diego Bay is underlain by a structurally controlled basin, its bottom a series of down-faulted blocks, probably in an area of tension at the junction between two right-stepping strands of the Rose Canyon fault zone.

The age of faulting within the Tijuana Flood Plain, San Diego Bay, and offshore bight areas is questionable. Though we are certain that rocks of early Pleistocene age are faulted, the question remains unanswered whether strata of late Pleistocene and Holocene age are faulted. Field data include (1) subbottom acoustic profiles described by Moore and Kennedy (1975); (2) Pleistocene fossils reported from a drill hole depth of 50 m beneath the Coronado Bridge in San Diego Bay (W. J. Zinsmeister, written communication); and (3) unconsolidated sand and shell fragments lithologically similar to the Bay Point Formation from the bottom of an exploratory hole drilled 60 m deep at the Naval Radio Station in Imperial Beach. Together, this evidence suggests that the uppermost part of the stratigraphic succession underlying San Diego Bay is late Pleistocene in age. In addition, the upper Pliocene San Diego Formation is not encountered at depths shallower than approximately 90 m below mean sea level at the mouth of the Tijuana River 2 km north of the U.S.-Mexican boundary (Hertlein and Grant, 1944). They also reported that the upper 90 m of section consists of alluvium. In the Tijuana Flood Plain (plate 2) water well data reported by Werner and Michitoshi (1967) suggests that the alluvium is less than half this thickness. Moore and Kennedy (1975) report that at least part of the section underlying San Diego Bay, Tijuana Flood Plain and offshore bight areas must belong to the lower Pleistocene Lindavista Formation (figure 2) and part to the upper Pleistocene Bay Point Formation.

The age assigned to faults within the Tijuana Valley and San Diego Bay area is based on the conclusion that the Bay Point Formation underlies San Diego Bay and is shown to be faulted on subbottom acoustic profiles (Moore and Kennedy, 1975) and that the uppermost few meters of faulted sediments shown on the same acoustic profiles are Holocene(?) in age.

GEOPHYSICAL ANOMALIES SOUTH OF SAN DIEGO BAY

A reconnaissance geophysical investigation was made during the current project, and consists of 21 ground magnetometer traverses, 2 seismic refraction traverses, and 1 gravity traverse (plate 2). Most of this work was done in the Tijuana River Valley, between the city of Imperial Beach and the U.S.-Mexican border. The measurements were made specifically in an attempt to locate and evaluate suspected faulting beneath the valley floor.

Magnetic Survey

A total of approximately 30 km of magnetometer traverses were completed in the area of study (18 of the 21 profiles made are shown on plate 2). Values of the vertical component of the earth's magnetic field were obtained at stations generally spaced at 30 m intervals (paced) by means of a Jalander fluxgate magnetometer with a reading accuracy of 10-15 gammas. In areas of steep magnetic gradients, readings were taken at intervals of 15 m or less for better detail. To eliminate errors due to diurnal effects and temperature changes, check readings were taken at a local base station, before and after each day's traverses were run.

The magnetic anomalies measured (plate 2) may be caused in part by variations in magnetic mineral content in either the alluvium, underlying sedimentary rocks, or basement igneous rocks. Some of these anomalies may be caused by differences in the magnetite content of rocks that have been juxtaposed by faulting. Wherever the probable cause of a particular anomaly was identified in the field as a man-made object, such as a pipeline, it is indicated on the magnetic profile plot (plate 2). The more prominent of the anomalies that may be caused by faulting are numbered on the magnetic profile and plan map (e.g., m1, m2, etc). Traverses M1-M1', M6-M6', M11-M11', M14-M14', M15-M15', M18-M18', and M19-M19' each show at least one possible fault anomaly.

Possible magnetic anomaly trends are shown in three areas (plates 1 and 2). These trends are based on correlation of data observed on traverses M6-M6' and M14-M14' in the south San Diego Bay area; traverses M11-M11' and M12-M12' in the vicinity of Otay Valley; and traverses M15-M15', M18-M18', and M19-M19', in the Tijuana River Flood Plain.

The anomalies (m1, m2) on traverses M6-M6' and M14-M14' are only small changes in the magnetic field intensity (20-30 gammas each), but they also represent an apparent change in the nature of the magnetic field which is less irregular to the west. These could represent a northwest striking fault offset of a relatively magnetic sedimentary rock unit which is very near the surface east of the possible fault. Traverses M11-M11' and M12-M12' both show a sharp change in background level of from 50 to 100 gammas near Otay Valley (m9, m10) which may represent a structural break with an approximate east trend.

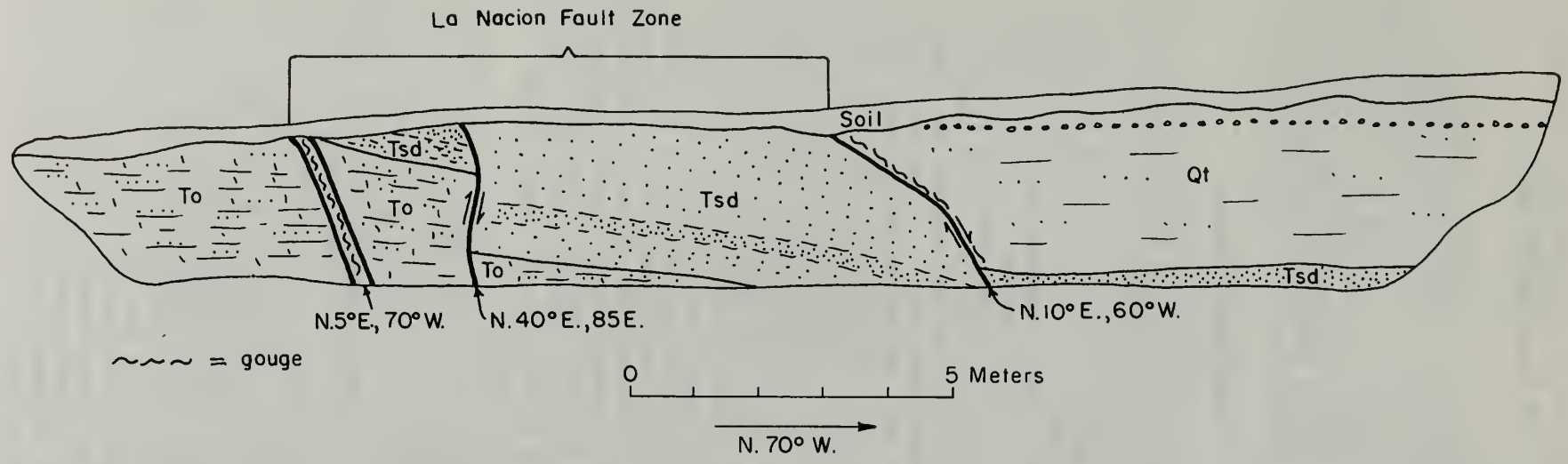


Figure 35. Juxtaposed strata of the Tertiary Otay (To) and San Diego Formations (Tsd) with Quaternary (?) age terrace deposits (Qt). View south in exploratory trench (see plate 1 for location).

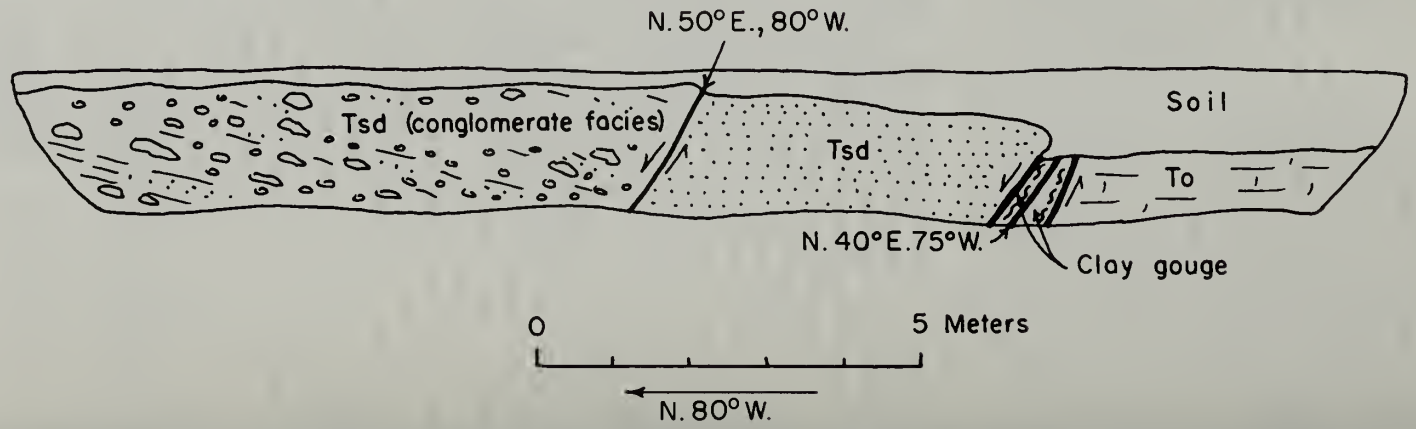


Figure 36. Strata of the San Diego Formation (Tsd) is faulted against the Otay Formation (To). The average strike of faults within the zone here is N. 40° E. and the dip is approximately 75° W. The soil horizon is thicker over the clay rich Otay Formation but is not faulted. View north in exploratory trench (see plate 1 for location).

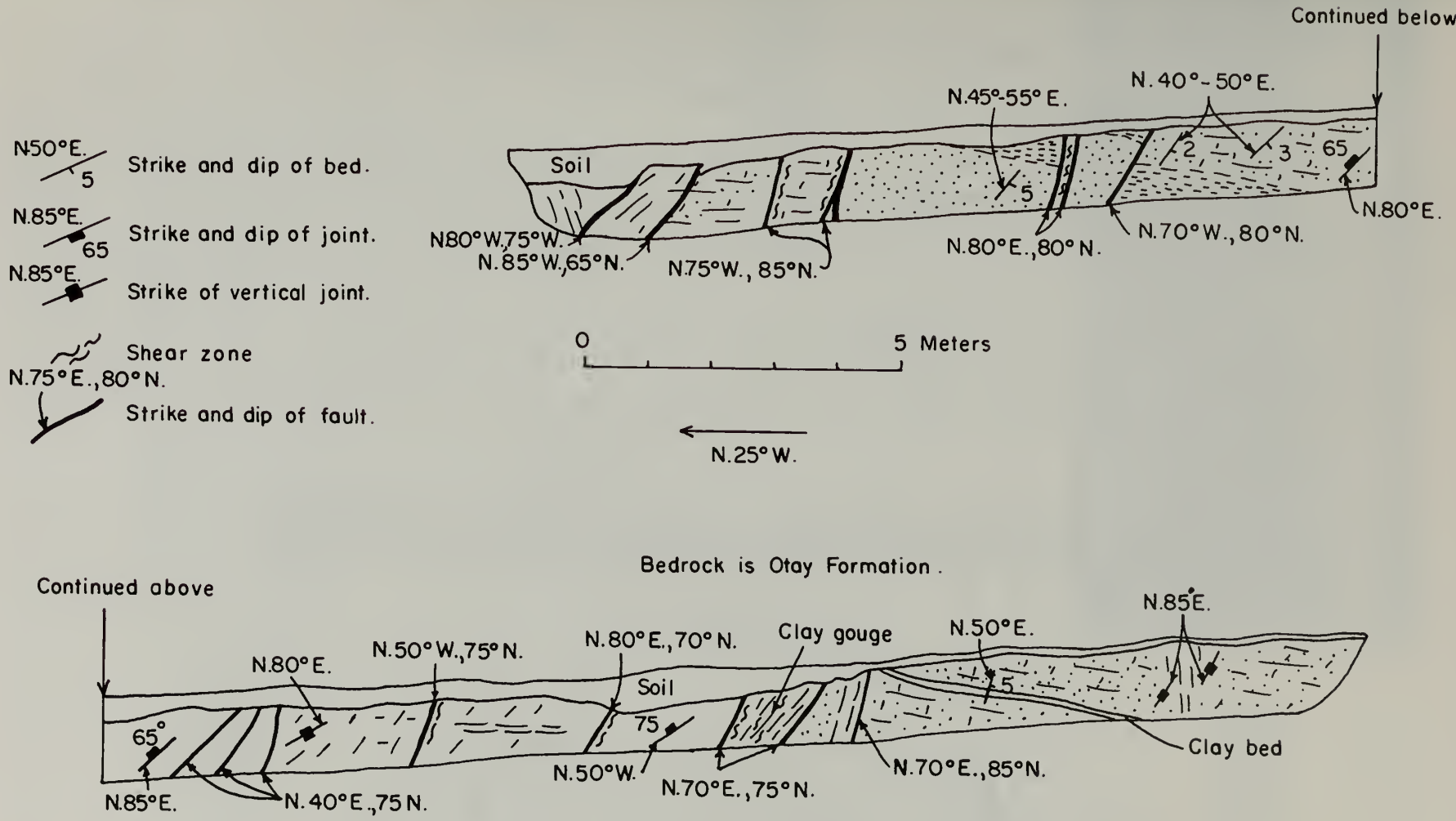


Figure 37. East-west striking faults intersect the La Nacion fault 1 km south of Otay Valley and may control the abrupt change in strike of the La Nacion fault here. View east in exploratory trench (see plate 1 for location).

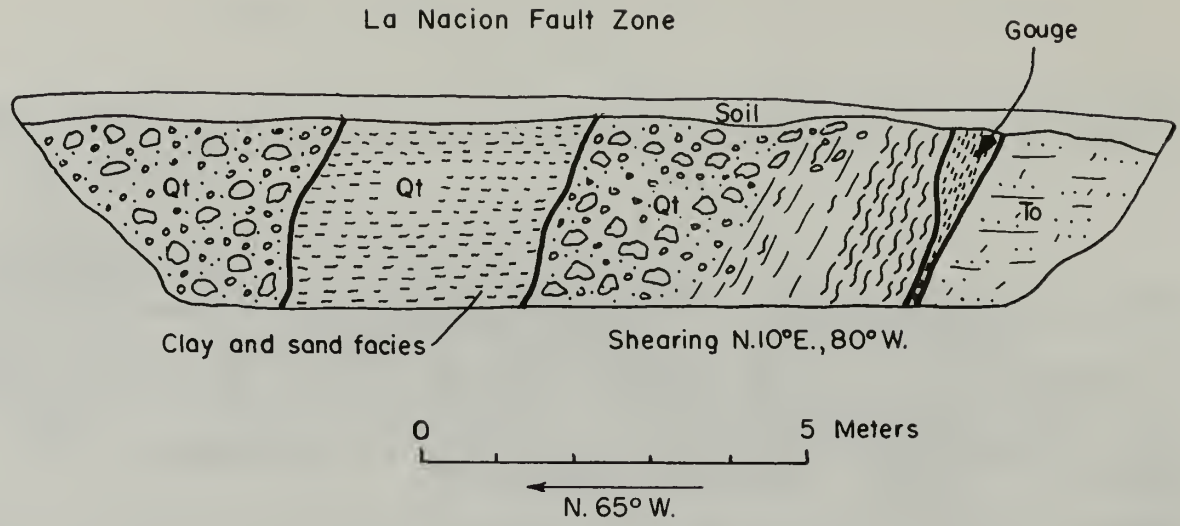


Figure 38. Quaternary terrace gravel and sand (Qt) are juxtaposed across a fault zone 3-4 m wide with rocks of the Otay Formation (To). Faults within the terrace deposits juxtapose a gravel and sand facies with a clay and sand facies. The average strike and dip of shearing within the fault zone is N. 10°E., 80°W. View north in an exploratory trench (see plate 1 for location).

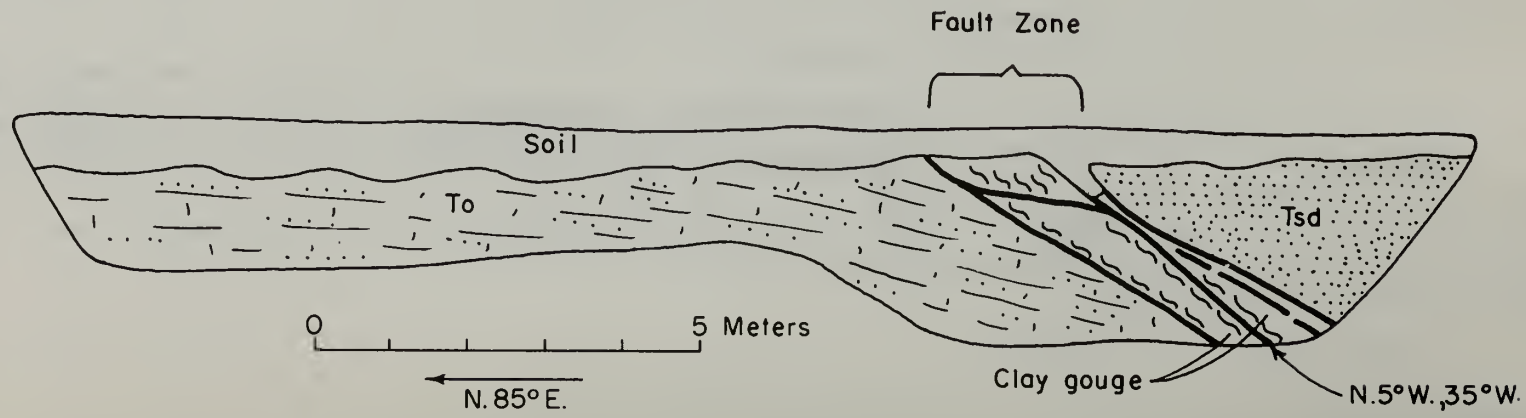


Figure 39. Juxtaposed San Diego Formation (Tsd) and Otay Formation (To). Soil lies adjacent to one branch of the fault as questionably the result of differential erosion along the fault plane and later deposit of soil. The soil horizon is extensively burrowed by animals and its contact with the underlying bedrock is not sharp. The apparent faulted soil horizon might be related to the burrowing. The average strike of the fault within the zone is N. 5° W. and the dip on an average 35° W. View south in an exploratory trench (see plate 1 for location).

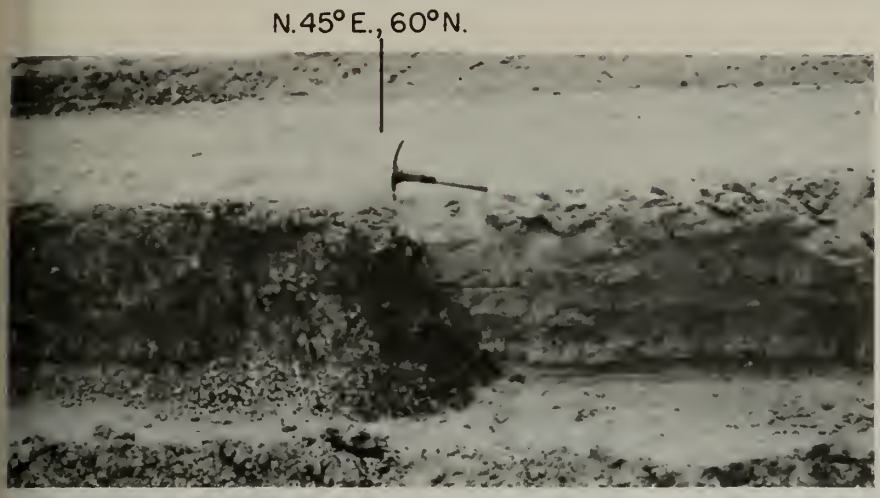


Figure 40. Faulted Quaternary terrace deposits vertically offset 2 m here. View west along Interstate Highway 805 (see plate 1 for location).

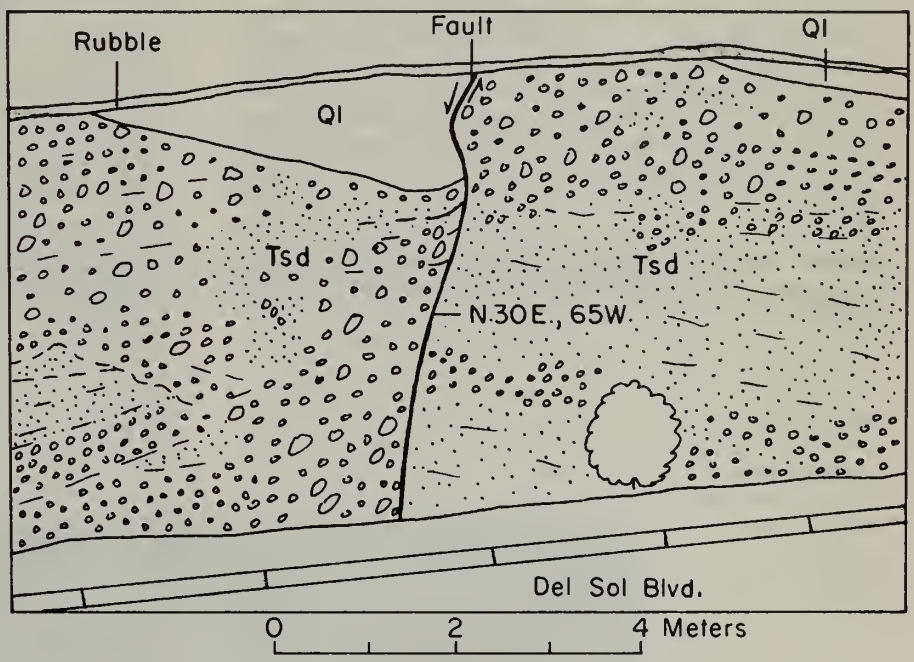


Figure 41. Road cut for Del Sol Boulevard. The Lindavista Formation (Ql) is vertically offset 2 m and is faulted against rocks of the San Diego Formation (Tsd). The fault strikes N. 30° E. and dips 65° W. View north (see plate 1 for location).

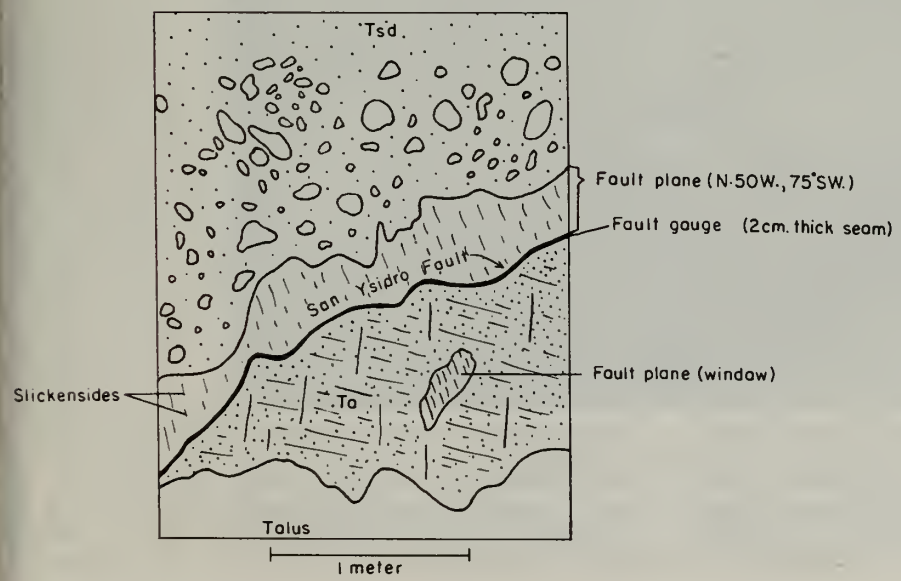


Figure 42. The San Ysidro fault juxtaposes strata of the San Diego (Tsd) and Otay (To) Formations. Approximately 30 m of vertical separation has occurred here with respect to these rocks. View west in rock quarry (see plate 1 for location).

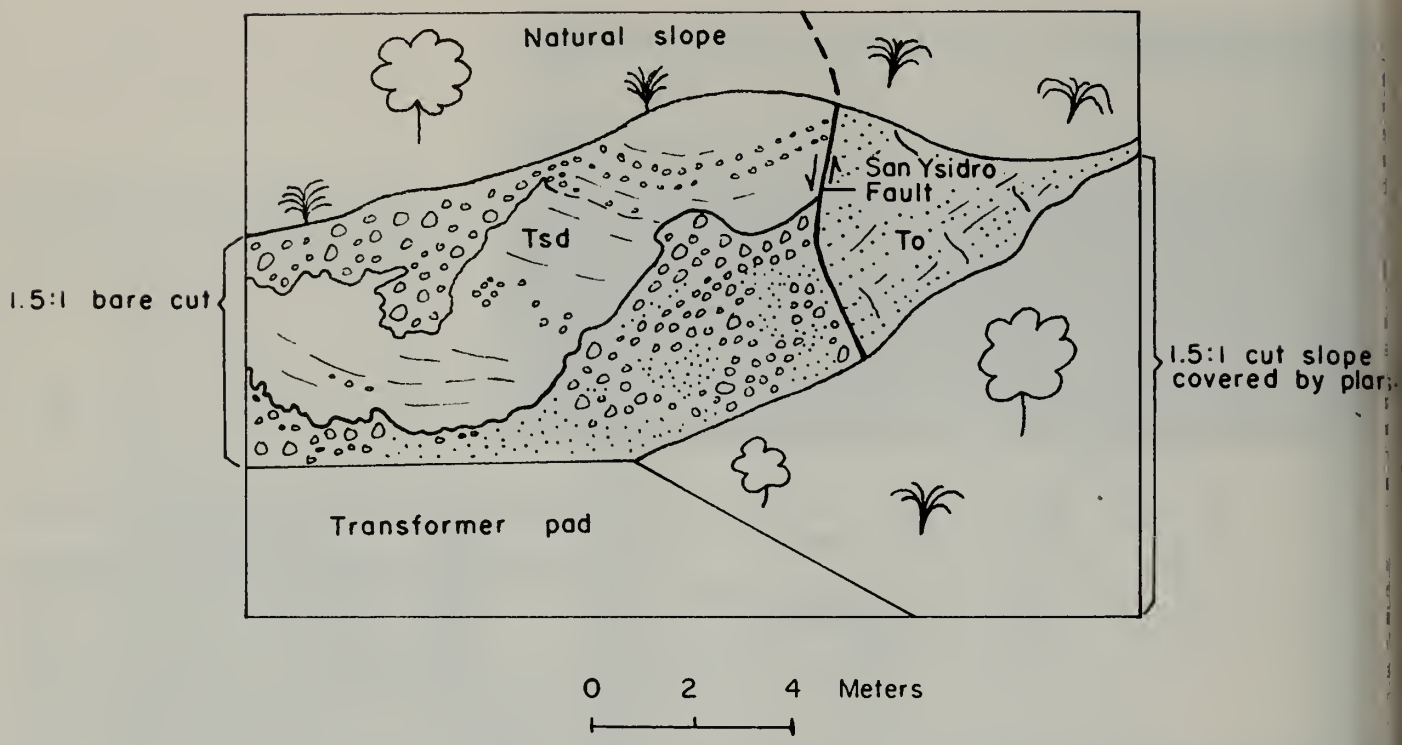


Figure 43. Rocks of a conglomeratic facies of the San Diego Formation (Tsd) lie in fault contact with sandstone of the Otay Formation (To). Approximately 70 m of vertical separation is associated with this break. The fault strikes N. 35° W. and dips 75° W. The west side of the fault is downdropped with respect to the east side. View north (see plate 1 for location).

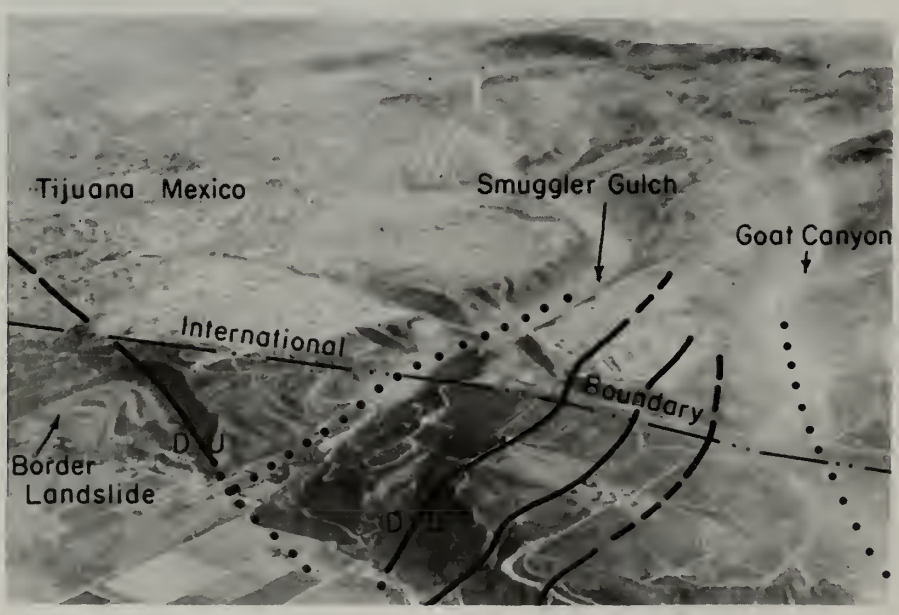


Figure 44. North and northwest striking faults show offset rocks of the Lindavista Formation. The fault shown adjacent to the Border Landslide juxtaposes rocks of the San Diego Formation and Lindavista Formation. The vertical separation there is on the order of 35 m. The three faults shown on the mesa between Smuggler Gulch and Goat Canyon together constitute the northern part of the Los Buenos fault mapped by Minch (1967) in Mexico. The faults shown are solid lines where accurately located, dotted where buried beneath unfaulted sediments, dashed where inferred. View south.

Traverses M15-M15', M18-M18', and M19-M19' all show similar anomalies (m4, m5, m6) which may represent a northwest-trending anomalous zone. On traverse M15-M15' the magnetic anomaly is approximately 100 gammas in amplitude, but toward the southeast the amplitude diminishes. However, on one intermediate traverse, M17-M17', no anomaly was found, which is puzzling if the anomalies on the other traverses represent a continuous zone. To the northwest a housing subdivision covers the possible continuation of this anomaly. East and northeast of San Isidro, traverses M8-M8', M9-M9', and M21-M21' each show a relatively steep rise in magnetic intensity of 100 to 200 gammas from near the floor of the valley to the top of Otay Mesa (m11, m12, m13). These magnetic gradients may be the result of faulting associated with the La Nacion and San Isidro faults.

On the west end of traverse M2-M2' and on traverse M20-M20', near the Pacific Ocean, a number of local anomalies (unnumbered) were observed, with amplitudes to 200 gammas or more. These may represent the concentrations of black sand, abundant in magnetite, that are known to exist in these areas. Elsewhere in the Tijuana Flood Plain area, few, if any, anomalies are large enough in amplitude to be significant or to be traced from one traverse line to another. One anomaly (m8) was marked on line M1-M1' near the intersection of this line with 19th Street where the apparent change in magnetic intensity level is about 80 gammas. The presence of at least two artifacts in this area made of steel reinforced concrete make interpretation of this anomaly uncertain. No anomaly was shown by seismic data in this area. Future magnetic investigations in the San Diego area should include additional traverses east of Interstate Highway 5, within the Tijuana River Valley, to examine in more detail the possible relationship between faulting and such anomalies.

Gravity Survey

A La Coste-Romberg geodetic gravity meter (G129) was used for the survey, and station elevations were determined with a level. Gravity values were corrected for meter drift and tidal effects and reduced to sea level datum using a density of 2.67 g/cm^3 (grams per cubic centimeter). One east-west gravity traverse, G1-G1', approximately 3,200 m long with a station interval of 60 m, was run along Sunset Avenue, centered on 19th Street. This traverse coincides with part of magnetometer traverse M1-M1'. The purpose of this traverse was to investigate the questionable magnetic anomaly (m8) noted in the previous section, but results were inconclusive.

The gravity traverse (plate 2) shows an overall gentle gradient tending toward higher values toward the east. The gradient increases its slope slightly east of 19th Street, otherwise there is no evidence of any gravity anomaly that might correspond to the magnetic anomaly in this area. This fact does not necessarily rule out the possibility of a fault associated with the magnetic anomaly, however. Future gravity measurements in the San Diego area should include a continuation of this gravity traverse both west and east through the area near 27th Street where both seismic and magnetic data suggest a possible fault.

Seismic Survey

Seismic observations were made using a geophone cable that is designed in even numbered feet. The results of the seismic data are given therefore in both feet and meters. The geophone cable is 1,100 ft (feet) (335 m) long and has 12 geophones at even 100 ft (30 m) intervals. A Midwestern portable refraction seismic unit was used to record the data. The energy source was 40 percent dynamite in amounts of 1 to 5 pounds buried in hand-dug holes that varied from 3 to 7 feet deep. Data were collected by recording five detonations at each geophone spread: one at each end, one in the middle, and two at offset locations approximately 1,100 ft (335 m) from each end of the spread. The effective depth penetration of the energy varied from a minimum of about 200 ft (61 m) to a maximum of about 500 ft (150 m) depending upon the seismic characteristics of the underlying rocks.

Two seismic traverses, S1-S1' and S2-S2', totaling approximately 18,500 ft (5,600 m) in length were obtained in the Tijuana Valley area (plate 2).

The interpretations of the seismic profiles are shown on plate 2. The quality of most of the field data was good except for the eastern part of traverse S1-S1' on Sunset Avenue. Here the first-arrival energy was characteristically weak and sometimes could not be identified on the far geophones. Even in these cases, however, the depth to the principal shallow refracting layer could be determined at least at the end points of the geophone spreads. In all other areas, depths to the refracting layers were determined at each geophone location.

Traverses S1-S1' and S2-S2' both revealed a near surface zone with an average velocity of about 800 fps (feet per second) (240 mps [meters per second]) that varies about 10 to 50 ft (3 to 15 m) in thickness (table 1). Surface material, which may represent this layer, consists of micaceous sand, silt, hardpan, coarse gravels, and a few boulders—probably recent alluvium. Underlying the surface layer is a unit that has an average velocity of about 6,000 fps (1,800 mps). On traverse S1-S1', the velocity is slightly less than this on the west end but between 6,000 and 7,000 fps (1,800 and 2,000 mps) on the east end. An exploratory bore hole, drilled during the course of this study, along seismic line S1-S1' near station 3,200 encountered the water table 20 ft (6 m) below the surface. This depth correlates with the depth of the seismic refraction at the same location. If lower velocity refractions (less than 5,700 fps) lie beneath the water table in this area, they would not be recorded. Therefore, the alluvium thickness based on these seismic traverses is speculative.

Table 1. Summary of seismic data—south San Diego area.

Seismic profile	Length and location	Number and length of geophone spreads	Seismic layers detected	Range in seismic velocities of layers	Range in thickness of seismic layer	Rock type
S1-S1'	11,800 ft (3,597 m) long on Sunset Avenue	Ten @ 1,100 ft (335.28 m) each	3	Layer 1: 800 fps (240 mps)	10-50 ft (3-15 m)	Alluvium?
				Layer 2: 5,700-7,000 fps (1,700-2,100 mps)	200-600 ft (61-183 m)	?
				Layer 3: 8,500 fps (2,600 mps)	-----	?
S2-S2'	6,600 ft (2,012 m) long on 19th Street	Six @ 1,100 ft (335.28 m) each	4	Layer 1: 800 fps (240 mps)	10-40 ft (3-12 m)	Alluvium?
				Layer 2: 2,500-3,000 fps (760-910 mps)	0-65 ft (0-20 m)	Older alluvium?
				Layer 3: 5,500-6,000 fps (1,700-2,100 mps)	350-500 ft (107-152 m)	?
				Layer 4: 8,500 fps (2,600 mps)	-----	?

As indicated on the seismic profiles (plate 2), except for an apparent offset of about 20 ft (6 m) near 27th Street, the surface of the 6,000 fps (1,800 mps) layer shows little or no evidence of possible fault offsets. West of 27th Street, this layer appears to dip gently downward to the east; east of 27th Street, it appears to be nearly horizontal. The apparent offset happens to lie in a short gap left between geophone spreads, exactly at 27th Street. This seismic anomaly is located in close proximity to magnetic anomaly (m 5) on traverse M18-M18'. However, magnetic traverse M1-M1' on Sunset Avenue apparently does not show this anomaly.

Seismic traverse S1-S1' shows no evidence of an offset or anomaly near 19th Street that might correspond to magnetic anomaly m8 on traverse M1-M1'.

In some places along seismic traverse S1-S1', there appears a weak indication of a deeper seismic horizon with a velocity of about 8,500 fps (2,600 mps). By assuming that a stratum with a velocity of 8,500 fps (2,600 mps) extends generally under the west portion of the area, the minimum depths to the velocity interface were determined. Along the entire traverse S2-S2' and on the west half of S1-S1', this minimum depth ranges from approximately 400 to 600 ft (122 to 183 m). On the east half of the S1-S1' traverse, this depth appears to be about 200 ft (61 m). These results suggest a possible vertical displacement of about 300 ft (91 m) down to the west, somewhere between 19th Street and Hollister Street, although no corresponding offset is indicated in the overlying 600 fps (183 mps) layer in this area.

The south half of seismic traverse S2-S2' shows, in addition to the near-surface 800 fps (240 mps) and underlying 6,000 fps (2,100 mps) layers, a zone with an intermediate velocity of about 3,000 fps (910 mps). This zone has its maximum thickness, about 65 ft (20 m), just north of Monument Road. The 3,000 fps (910 mps) zone could represent an older buried channel of the Tijuana River. About 2,000 ft (610 m) north of Monument Road, a section about 300 ft (91 m) long of the 6,000 fps (2,134 mps) layer is elevated about 20 to 30 ft (6 to 9 m) relative to the adjoining areas. As indicated on plate 2, the elevated section has a horst-like appearance that suggests possible faulting. These elevated offsets could represent northwestward extensions of one or more of the faults mapped to the southeast near the Mexican border (plate 1).

Future seismic investigations in the San Diego area should be planned to investigate the following:

(1) The apparent offset in the 6,000 fps (2,100 mps) layer on traverse S1-S1' near 27th Street and the possible associated magnetic anomalies;

(2) the possible fault offset in the 8,500 fps (2,600 mps) layer between 19th and Hollister Streets; and

(3) possible extensions of the suspected Tijuana River Channel intermediate velocity zone (3,000 fps/910 mps) and apparent associated faulting, both east and west of where it was observed on the south part of traverse S2-S2'.

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2 plates
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THOMAS E. GAY JR., ACTING STATE GEOLOGIST

STATE OF CALIFORNIA
THE RESOURCES AGENCY
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FAULTING IN THE SAN DIEGO AREA
SPECIAL REPORT 123, PLATE 1

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MAP SHOWING CHARACTER AND RECENCY OF FAULTING IN THE SAN DIEGO AREA CALIFORNIA

BY
MICHAEL P. KENNEDY AND SEAN SIANG TAN
1975

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EXPLANATION

U 0 50 D
FAULT
Solid line where existence is certain, dashed where inferred, dotted where concealed by Holocene alluvium, U, upthrown side, D, downthrown side, single arrow and number indicate dip of fault plane, double arrows indicate sense of lateral slip.

FAULT ZONE

FAULT INFERRED FROM PHOTOGRAPHIC EVIDENCE

FAULT INFERRED FROM GEOPHYSICAL EVIDENCE
See plate 2 for magnetic, gravity and seismic data used for inference.

FAULT UNDERLYING SAN DIEGO BAY AND OFFSHORE AREA
(Modified from Moore and Kennedy in press).

SYNCLINE

ANTICLINE

(41)
LOCATION OF TEXT FIGURE

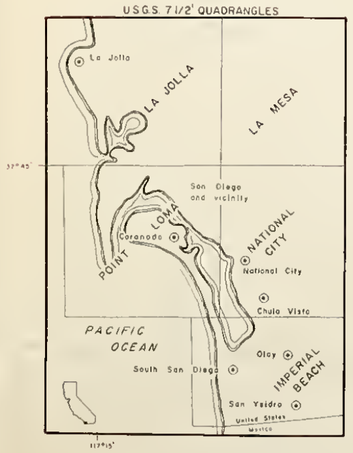
T/h
AGE OF FAULT MOVEMENT

Capital letter indicates age of strata known to be faulted, lower case letter indicates age of strata known to be unfaulted. (See key below and text discussion of ages of strata faulted and not faulted).

Key to age of fault movement symbols

Strata and age	Faulted	Not faulted
HOLOCENE (Soil, alluvium, slopewash)	H	h
LATE PLEISTOCENE (Bay Point Formation)	L	l
EARLY PLEISTOCENE (Lindavista Formation)	Q	q
TERTIARY OR OLDER STRATA (San Diego Formation, Otay Formation, Poway Group, La Jolla Group, Rosario Group)	T	t

USGS 7 1/2' QUADRANGLES



TOPOGRAPHIC BASE BY U.S.G.S.
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SCALE 1:50,000
1/2 0 1 MILE
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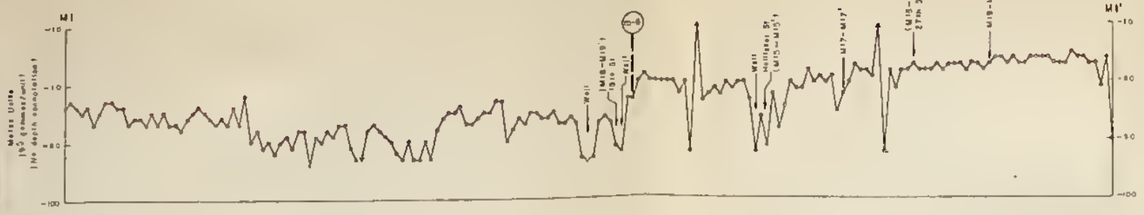
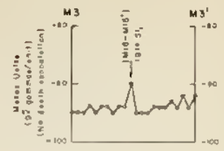
FAULTING IN THE SAN DIEGO AREA
SPECIAL REPORT 123, PLATE 2

MAGNETOMETER TRAVERSES

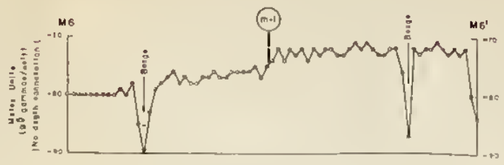
MAGNETOMETER TRAVERSE M1 — M1'



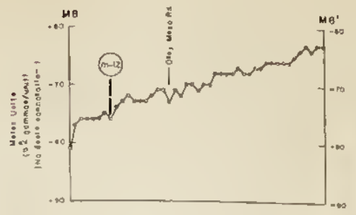
MAGNETOMETER TRAVERSE M3 — M3'



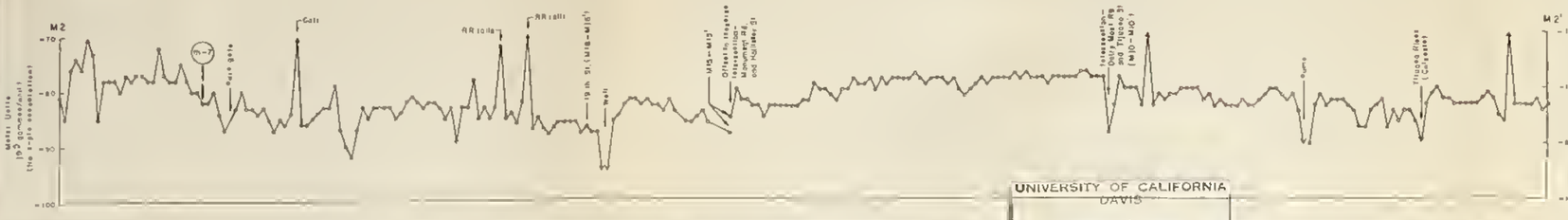
MAGNETOMETER TRAVERSE M6 — M6'



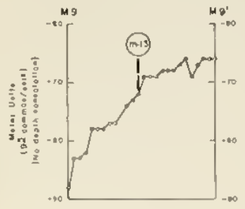
MAGNETOMETER TRAVERSE M8 — M8'



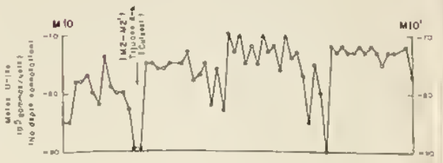
MAGNETOMETER TRAVERSE M2 — M2'



MAGNETOMETER TRAVERSE M9 — M9'



MAGNETOMETER TRAVERSE M10 — M10'



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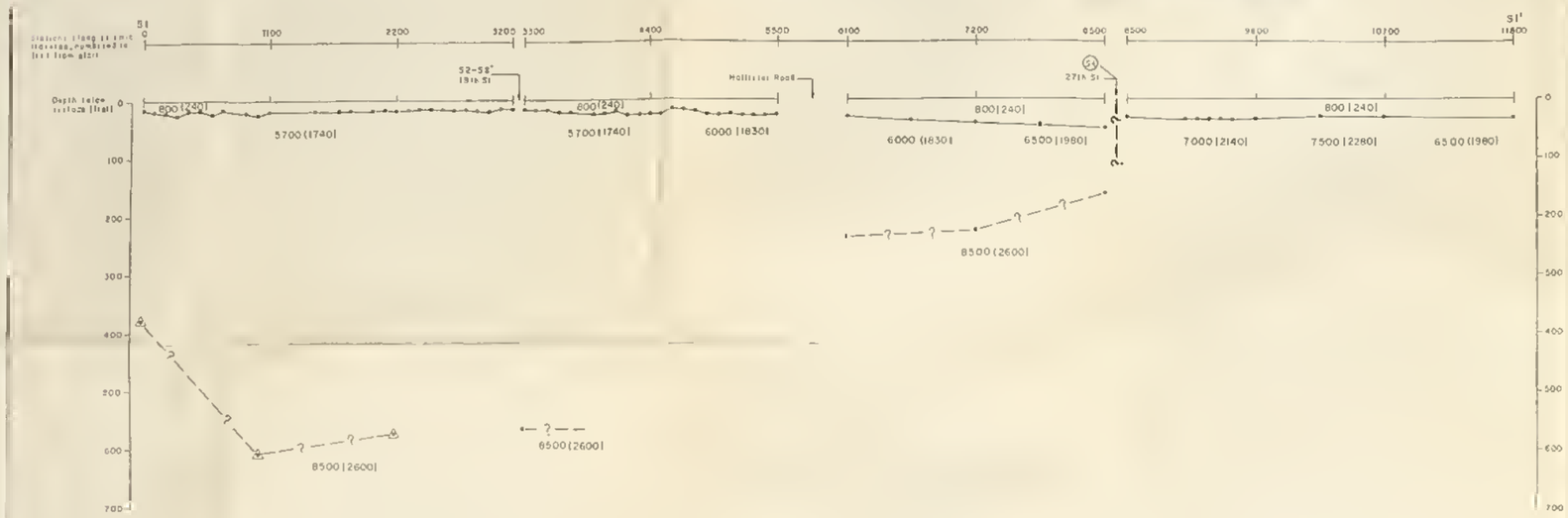
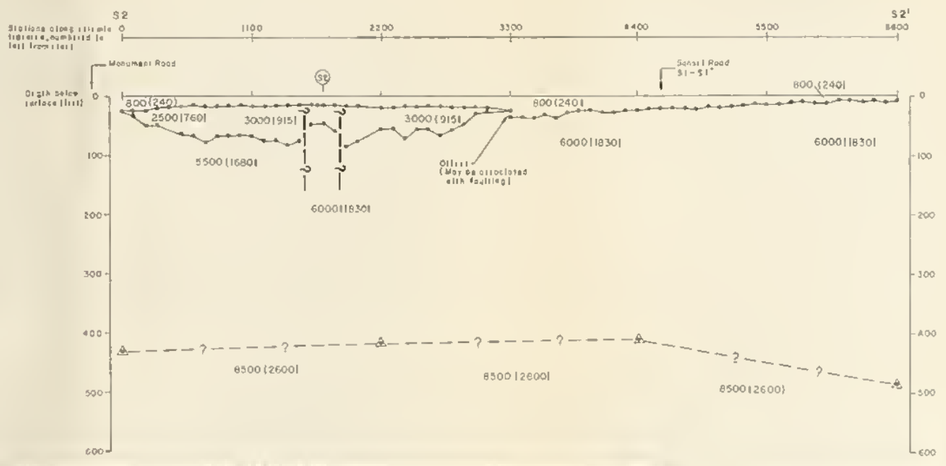
SEISMIC TRAVERSES

CROSS SECTION ALONG SEISMIC TRAVERSE S1 — S1'



CROSS SECTION ALONG SEISMIC TRAVERSE S2 — S2'



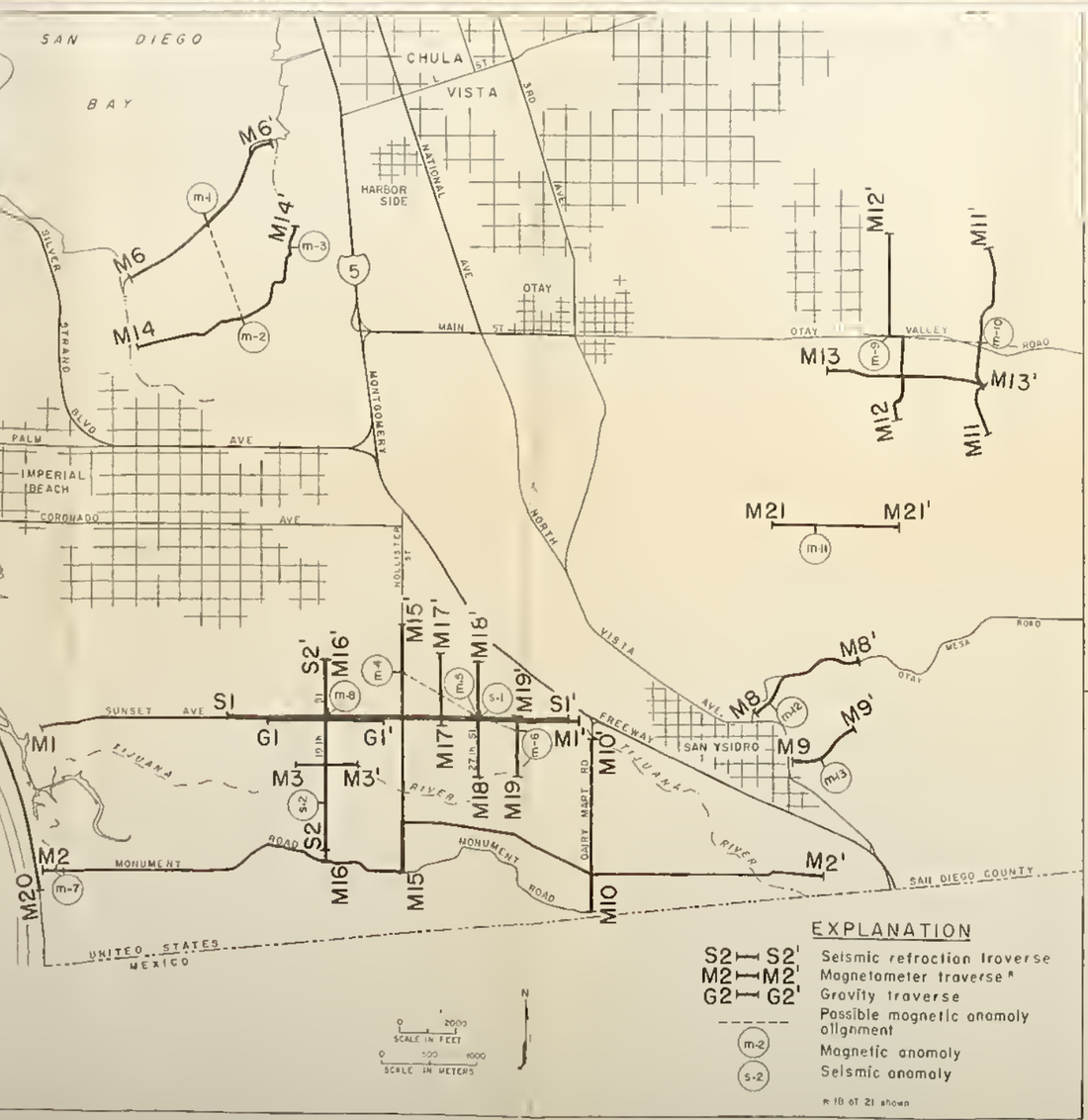
EXPLANATION FOR SEISMIC TRAVERSES

- Possible faulting
- Depth point
- Minimum depth point, assumed 6500 fps velocity
- 1000 (305) Velocity in feet per second (fps) Velocity in meter per second (mps)
- Seismic horizon
- (52) Anomalous area below numbered circle

HORIZONTAL SCALES

0 500 Scale in feet

0 500 Scale in Meters



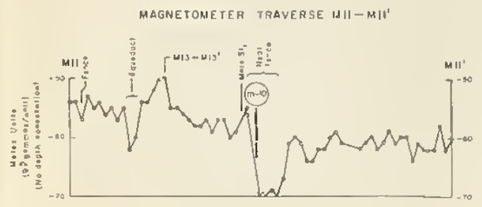
EXPLANATION

- S2 — S2' Seismic refraction traverse
- M2 — M2' Magnetometer traverse *
- G2 — G2' Gravity traverse
- Possible magnetic anomaly alignment
- (m-2) Magnetic anomaly
- (s-2) Seismic anomaly

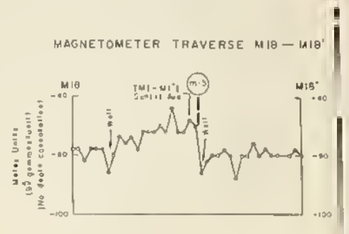
* 18 of 21 shown

Index map showing locations of seismic, magnetic and gravity traverses.

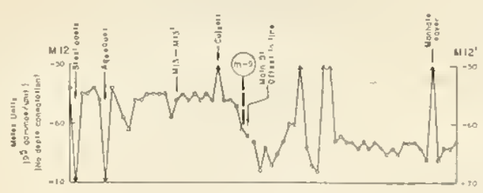
MAGNETOMETER TRAVERSE M11 — M11'



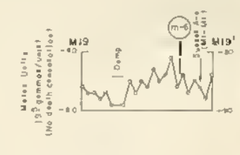
MAGNETOMETER TRAVERSE M18 — M18'



MAGNETOMETER TRAVERSE M12 — M12'

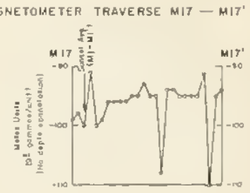


MAGNETOMETER TRAVERSE M19 — M19'



MAGNETOMETER TRAVERSE M13 — M13'

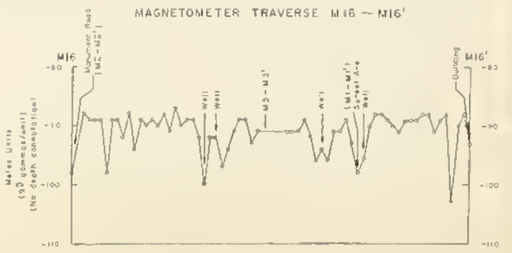
MAGNETOMETER TRAVERSE M17 — M17'



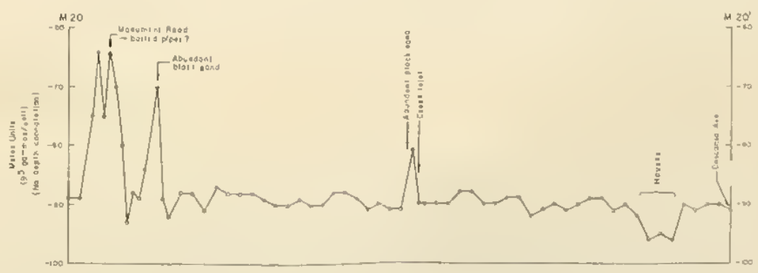
MAGNETOMETER TRAVERSE M14 — M14'

MAGNETOMETER TRAVERSES M15 — M15'

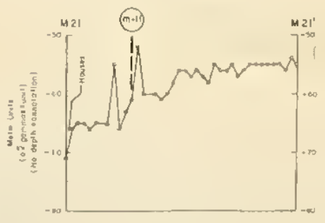
MAGNETOMETER TRAVERSE M16 — M16'



MAGNETOMETER TRAVERSE M 20 — M 20'



MAGNETOMETER TRAVERSE M21 — M21'



EXPLANATION FOR MAGNETOMETER TRAVERSES

- Magnetometer reading
- Data greater or less than plotted scale
- Vertical magnetic intensity levels
- (m2) Magnetic anomaly and number

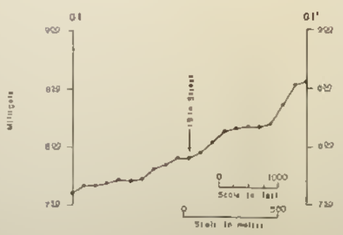
HORIZONTAL SCALES

0 1000 Scale in feet

0 500 1000 Scale in meters

GRAVITY TRAVERSE

GRAVITY TRAVERSE G1 — G1'



SEISMIC, MAGNETOMETER AND GRAVITY TRAVERSES SOUTH SAN DIEGO AREA, CALIFORNIA

CROSS SECTIONS CONSTRUCTED BY INTERPRETATION OF SEISMIC DATA

BY RODGER CHAPMAN AND GORDON CHASE

1974

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